ANNUAL REPORT OF THE
BOARD OF REGENTS OF

THE SMITHSONIAN INSTITUTION

SHOWING THE

OPERATIONS, EXPENDITURES, AND
CONDITION OF THE INSTITUTION
FOR THE YEAR ENDING JUNE 30

1929

(Publication 3034)

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON : 1930

For sale by the Superintendent of Documents, Washington, D. C. - - - - - - Price $1.75 (Cloth)

LETTER

FROM THE

SECRETARY OF THE SMITHSONIAN INSTITUTION

SUBMITTING

THE ANNUAL REPORT OF THE BOARD OF REGENTS OF THE INSTITUTION FOR THE YEAR ENDED JUNE 30, 1929

SMITHSONIAN INSTITUTION,
Washington, November 26, 1929.

To the Congress of the United States:

In accordance with section 5593 of the Revised Statutes of the United States, I have the honor, in behalf of the Board of Regents, to submit to Congress the annual report of the operations, expenditures, and condition of the Smithsonian Institution for the year ended June 30, 1929. I have the honor to be,

Very respectfully, your obedient servant,

C. G. ABBOT, *Secretary.*

CONTENTS

General Appendix

[1] In part governmentally supported.

LIST OF PLATES

ANNUAL REPORT OF THE BOARD OF REGENTS OF THE SMITHSONIAN INSTITUTION FOR THE YEAR ENDING JUNE 30, 1929

SUBJECTS

1. Annual report of the secretary, giving an account of the operations and condition of the Institution for the year ending June 30, 1929, with statistics of exchanges, etc.

2. Report of the executive committee of the Board of Regents, exhibiting the financial affairs of the Institution, including a statement of the Smithsonian fund, and receipts and expenditures for the year ending June 30, 1929.

3. Proceedings of the Board of Regents for the fiscal year ending June 30, 1929.

4. General appendix, comprising a selection of miscellaneous memoirs of interest to collaborators and correspondents of the Institution, teachers, and others engaged in the promotion of knowledge. These memoirs relate chiefly to the calendar year 1929.

THE SMITHSONIAN INSTITUTION

June 30, 1929

Presiding officer ex officio.—HERBERT HOOVER, President of the United States.
Chancellor.—WILLIAM HOWARD TAFT, Chief Justice of the United States.
Members of the Institution:

HERBERT HOOVER, President of the United States.
CHARLES CURTIS, Vice President of the United States.
WILLIAM HOWARD TAFT, Chief Justice of the United States.
HENRY L. STIMSON, Secretary of State.
ANDREW W. MELLON, Secretary of the Treasury.
JAMES W. GOOD, Secretary of War.
WILLIAM D. MITCHELL, Attorney General.
WALTER F. BROWN, Postmaster General.
CHARLES FRANCIS ADAMS, Secretary of the Navy.
RAY LYMAN WILBUR, Secretary of the Interior.
ARTHUR M. HYDE, Secretary of Agriculture.
ROBERT P. LAMONT, Secretary of Commerce.
JAMES JOHN DAVIS, Secretary of Labor.

Regents of the Institution:

WILLIAM HOWARD TAFT, Chief Justice of the United States, Chancellor.
CHARLES CURTIS, Vice President of the United States.
REED SMOOT, Member of the Senate.
JOSEPH T. ROBINSON, Member of the Senate.
CLAUDE A. SWANSON, Member of the Senate.
ALBERT JOHNSON, Member of the House of Representatives.
R. WALTON MOORE, Member of the House of Representatives.
WALTER H. NEWTON,[1] Member of the House of Representatives.
ROBERT S. BROOKINGS, citizen of Missouri.
IRWIN B. LAUGHLIN, citizen of Pennsylvania.
FREDERIC A. DELANO, citizen of Washington, D. C.
DWIGHT W. MORROW, citizen of New Jersey.
CHARLES EVANS HUGHES, citizen of New York.
JOHN C. MERRIAM, citizen of Washington, D. C.

Executive committee.—FREDERIC A. DELANO, R. WALTON MOORE, JOHN C. MERRIAM.
Secretary.—CHARLES G. ABBOT.
Assistant Secretary.—ALEXANDER WETMORE.
Chief Clerk.—HARRY W. DORSEY.
Treasurer and disbursing agent.—NICHOLAS W. DORSEY.
Editor.—WEBSTER P. TRUE.
Librarian.—WILLIAM L. CORBIN.
Appointment clerk.—JAMES G. TRAYLOR.
Property clerk.—JAMES H. HILL.

---

[1] Resigned June 30, 1929; Hon. Robert Luce appointed on July 1, 1929, to succeed him.

NATIONAL MUSEUM

Assistant Secretary (in charge).—Alexander Wetmore.
Administrative assistant to the Secretary.—William de C. Ravenel.
Head curators.—Walter Hough, Leonhard Stejneger, George P. Merrill.
Curators.—Paul Bartsch, Ray S. Bassler, Theodore T. Belote, Austin H. Clark, Frank W. Clarke, Frederick V. Coville, Charles W. Gilmore, Walter Hough, Leland O. Howard, Aleš Hrdlička, Neil M. Judd, Herbert W. Krieger, Frederick L. Lewton, George P. Merrill, Gerrit S. Miller, Jr., Carl W. Mitman, Waldo L. Schmitt, Leonhard Stejneger.
Associate curators.—John M. Aldrich, Chester G. Gilbert, Ellsworth P. Killip, William R. Maxon, Charles E. Resser, Charles W. Richmond, David White.
Chief of correspondence and documents.—Herbert S. Bryant.
Disbursing agent.—Nicholas W. Dorsey.
Superintendent of buildings and labor.—James S. Goldsmith.
Editor.—Marcus Benjamin.
Assistant Librarian.—Isabel L. Towner.
Photographer.—Arthur J. Olmsted.
Property clerk.—William A. Knowles.
Engineer.—Clayton R. Denmark.

NATIONAL GALLERY OF ART

Director.—William H. Holmes.

FREER GALLERY OF ART

Curator.—John Ellerton Lodge.
Associate curator.—Carl Whiting Bishop.
Assistant curator.—Grace Dunham Guest.
Associate.—Katharine Nash Rhoades.
Superintendent.—John Bundy.

BUREAU OF AMERICAN ETHNOLOGY

Chief.—Matthew W. Stirling.
Ethnologists.—John P. Harrington, John N. B. Hewitt, Francis La Flesche, Truman Michelson, John R. Swanton.
Archeologist.—Frank H. H. Roberts, Jr.
Editor.—Stanley Searles.
Librarian.—Ella Leary.
Illustrator.—De Lancey Gill.

INTERNATIONAL EXCHANGES

Secretary (in charge).—Charles G. Abbot.
Chief clerk.—Coates W. Shoemaker.

NATIONAL ZOOLOGICAL PARK

Director.—William M. Mann.
Assistant director.—Arthur B. Baker.

ASTROPHYSICAL OBSERVATORY

Director.—Charles G. Abbot.
Research assistant.—Frederick E. Fowle, Jr.
Research assistant.—Loyal B. Aldrich.

DIVISION OF RADIATION AND ORGANISMS

Research associate in charge.—Frederick S. Brackett.
Consulting plant physiologist.—Earl S. Johnston.
Research assistant.—Leland B. Clark.

REGIONAL BUREAU FOR THE UNITED STATES, INTERNATIONAL CATALOGUE OF SCIENTIFIC LITERATURE

Assistant in charge.—Leonard C. Gunnell

REPORT

OF THE

SECRETARY OF THE SMITHSONIAN INSTITUTION

C. G. Abbot

FOR THE YEAR ENDING JUNE 30, 1929

To the Board of Regents of the Smithsonian Institution:

Gentlemen: I have the honor to submit herewith my report showing the activities and condition of the Smithsonian Institution and the Government bureaus under its administrative charge during the fiscal year ended June 30, 1929. The first 22 pages contain a summary account of the affairs of the Institution. Appendixes 1 to 11 give more detailed reports of the operations of the United States National Museum, the National Gallery of Art, the Freer Gallery of Art, the Bureau of American Ethnology, the International Exchanges, the National Zoological Park, the Astrophysical Observatory, the Division of Radiation and Organisms, the United States Regional Bureau of the International Catalogue of Scientific Literature, the Smithsonian library, and of the publications issued under the direction of the Institution; and Appendix 12 contains a list of subscribers up to November 15, 1929, to the James Smithson Memorial Edition of the Smithsonian Scientific Series.

THE SMITHSONIAN INSTITUTION

OUTSTANDING EVENTS OF THE YEAR

The year has been gratifyingly and unexpectedly rich in progress. Among many items of importance it is even hard to select the greatest. The National Government and many friends of the Institution have added materially to its income.—Mr. John Gellatly, of New York, has made the gift of his extensive collection comprising classic American and European paintings, outstanding specimens of jewellers' art, tapestries, furniture, and oriental art, valued altogether at several million dollars, to the Smithsonian for eventual exhibition in the National Gallery.—A new department, the Division of Radiation and Organisms, has been added to the research laboratories of

the Institution, and already has made notable headway under Dr. F. S. Brackett, its director, in its preparation to add fundamental data to our knowledge of the dependence on radiation of the growth of plants and the health of animals and human beings. In connection with this division, four rooms in the basement and four in the flag tower of the Smithsonian Building, heretofore of little value, have been fitted for laboratories and offices, and much modern laboratory furniture and apparatus have been purchased.—Four volumes of the 12-volume set entitled "Smithsonian Scientific Series" have been issued by the publishers in beautiful form. Many expressions of pleased appreciation have been received from subscribers, and the royalties to the Institution, as author, to be used for promoting research and publication, have exceeded anticipation. The remaining eight volumes of the series are far advanced in preparation, and will be at least equally as interesting and beautiful as those already issued.—Many expeditions of excellent accomplishment have gone forth from the National Museum, the Bureau of American Ethnology, the Astrophysical Observatory, and the Freer Gallery to remote quarters of the earth.—Numerous monographs and original research articles have been published, embodying valuable results of observation.—By cooperation with the War Department the military exhibits in the National Museum have been entirely rearranged. Along with this have gone other extensive improvements in the exhibitions.—Under the act of 1928, by which Congress appropriated $20,000 to promote cooperative investigations in ethnology and archeology in the several States to be expended at the discretion of the Smithsonian, allotments totaling over $9,000 have been made for projects in 10 different States.—Great progress has been made in the improvement of the library.—A new building for birds, believed to be the best for this purpose in the whole world, has been added to the equipment of the National Zoological Park. Congress has gratifyingly made provision for a new reptile house equally well designed.—All of these and many other matters of scarcely less interest will be mentioned in more detail in the pages which immediately follow, as well as in the special reports of the different branches of the Institution.

THE ESTABLISHMENT

The Smithsonian Institution was created by act of Congress in 1846, according to the terms of the will of James Smithson, of England, who, in 1826, bequeathed his property to the United States of America "to found at Washington, under the name of the Smithsonian Institution, an establishment for the increase and diffusion of knowledge among men." In receiving the property and accepting the trust, Congress determined that the Federal Government was

without authority to administer the trust directly, and therefore constituted an "establishment" whose statutory members are "the President, the Vice President, the Chief Justice, and the heads of the executive departments."

THE BOARD OF REGENTS

The affairs of the Institution are administered by a Board of Regents whose membership consists of "the Vice President, the Chief Justice, three members of the Senate, and three Members of the House of Representatives, together with six other persons other than Members of Congress, two of whom shall be resident in the city of Washington and the other four shall be inhabitants of some State, but no two of them the same State." One of the Regents is elected chancellor by the board; in the past the selection has fallen upon the Vice President or the Chief Justice; and a suitable person is chosen by the Regents as Secretary of the Institution, who is also secretary of the Board of Regents, and the executive officer directly in charge of the Institution's activities.

The only change occurring in the personnel of the board during the year was the termination of the Vice Presidency of General Dawes, and the succession of Charles Curtis, March 4, 1929.

The roll of the Regents at the close of the fiscal year was as follows: William H. Taft, Chief Justice of the United States, chancellor; Charles Curtis, Vice President of the United States; members from the Senate, Reed Smoot, Joseph T. Robinson, Claude A. Swanson; members from the House of Representatives, Albert Johnson, R. Walton Moore, Walter H. Newton;[1] citizen members, Robert S. Brookings, Missouri; Irwin B. Laughlin, Pennsylvania; Frederic A. Delano, Washington, D. C.; Dwight W. Morrow, New Jersey; Charles Evans Hughes, New York; and John C. Merriam, Washington, D. C.

FINANCES

The permanent investments of the Institution consist of the following:

Total endowment for general or specific purposes (exclusive of Freer funds)	$1, 648, 389. 45
Itemized as follows:	
Deposited in the Treasury of the United States, as provided by law	1, 000, 000. 00

[1] Resigned June 30, 1929; Hon. Robert Luce, of Massachusetts, appointed on July 1, 1929, to succeed him.

Deposited in the consolidated fund:	
Miscellaneous securities, etc., either purchased or acquired by gift; cost or value at date acquired	$557,056.95
Springer, Frank, fund for researches, etc. (bonds)	30,000.00
Walcott, Charles D. and Mary Vaux, fund for researches, etc. (stocks)	11,520.00
Younger, Helen Walcott, fund (real-estate notes and stock held in trust)	49,812.50
Total	1,648,389.45

The invested funds of the Institution are described as follows:

Fund	United States Treasury	Consolidated fund	Separate funds	Total
Avery fund	$14,000.00	$48,678.65		$62,678.65
Bacon, Virginia Purdy, fund		65,494.44		65,494.44
Baird, Lucy H., fund		1,978.22		1,978.22
Canfield Collection fund		49,270.77		49,270.77
Casey, Thomas L., fund		3,212.83		3,212.83
Chamberlain fund		36,811.50		36,811.50
Endowment fund		61,427.74		61,427.74
Habel fund	500.00			500.00
Hachenberg fund		5,259.50		5,259.50
Hamilton fund	2,500.00	526.85		3,026.85
Henry, Caroline, fund		1,580.95		1,580.95
Hodgkins fund:				
General	116,000.00	39,204.10		155,204.10
Specific	100,000.00			100,000.00
Hughes, Bruce, fund		17,856.12		17,856.12
Myer, Catherine W, fund		20,672.33		20,672.33
Pell, Cornelia Livingston, fund		3,156.10		3,156.10
Poore, Lucy T. and George W., fund	26,670.00	29,220.73		55,890.73
Reid, Addison T., fund	11,000.00	11,569.23		22,569.23
Rhees fund	590.00	618.33		1,208.33
Roebling fund		157,758.93		157,758.93
Sanford, George H., fund	1,100.00	1,163.88		2,263.88
Smithson fund	727,640.00	1,595.75		729,235.75
Springer, Frank, fund			$30,000.00	30,000.00
Walcott, Charles D. and Mary Vaux, fund			11,520.00	11,520.00
Younger, Helen Walcott, fund			49,812.50	49,812.50
Total	1,000,000.00	557,056.95	91,332.50	1,648,389.45

The Institution gratefully acknowledges gifts from the following donors:

Dr. W. L. Abbott, for further contribution for archeological explorations in Dominican Republic and for expeditions to Haiti and Santo Domingo.

Mr. Francis B. Atkinson, for general endowment fund of the Institution.

Carnegie Corporation, for expenses of exhibition of Ranger paintings.

I. M. Casanowicz, estate of, for general endowment fund of the Institution.

Mrs. Laura Welsh Casey, further contribution to the Thomas Lincoln Casey fund, for researches in Coleoptera.

Hon. Charles G. Dawes, for search in Spain for valuable ancient documents.

Mr. Fairfax Harrison, for general endowment fund of the Institution.

Hon. Irwin B. Laughlin, for general endowment fund of the Institution.

Mr. Dean Mathey, for general endowment fund of the Institution.

Missouri Historical Society, for further studies of the language of the Osage Indians.

Research Corporation, further contribution for research in radiation.

Rockefeller Foundation, for research in radiation by Dr. Anders K. Ångström.

Mr. John A. Roebling, further contribution for researches in solar radiation and study of world weather records.

Stanco (Inc.), for botanical expedition to Peru.

Messrs. E. H. Siegler and C. H. Popenoe, for valuable patents covering insecticide.

Freer Gallery of Art.—The invested funds of the Freer bequest are classified as follows:

Court and grounds fund	$574, 524. 12
Court and grounds maintenance fund	148, 112. 53
Curator fund	596, 301. 18
Residuary legacy	3, 917, 116. 19
Total	5, 236, 054. 02

The practice of depositing on time in local trust companies and banks such revenues as may be spared temporarily has been continued during the past year, and interest on these deposits has amounted to $5,631.82.

Cash balances, receipts and disbursements during the fiscal year [2]

Cash balance on hand June 30, 1928		$238, 369. 41
Receipts:		
Cash from invested endowments and from miscellaneous sources for general use of the Institution	$61, 309. 56	
Cash for increase of endowments for specific use	3, 000. 00	
Cash for increase of endowments for general use	6, 535. 00	
Cash gifts for specific use (not to be invested)	50, 111. 01	
Cash received as royalties from sales of Smithsonian Scientific Series [3]	14, 454. 01	
Cash gain from sale, etc., of securities (to be invested)	22, 944. 95	
Cash income from endowments for specific use other than Freer endowment, and from miscellaneous sources	82, 425, 70	
Total receipts other than Freer endowment		240, 780. 23
Cash income from Freer endowment:		
Income from investments	282, 435. 13	
Gain from sale, etc., of securities (to be invested)	940, 476. 80	
		1, 222, 911. 93
		1, 702, 061. 57

[2] This statement does not include Government appropriations under the administrative charge of the Institution.

[3] Under resolution of the Board of Regents three-fourths of this income is credited to the permanent endowment fund of the Institution and one-fourth is made expendable for general purposes.

Disbursements:		
General work of the Institution—		
Buildings—care, repair, and alteration	$11,564.59	
Furniture and fixtures	746.06	
General administration [4]	20,652.66	
Library	3,006.55	
Publications (comprising preparation, printing, and distribution)	16,865.75	
Researches and explorations	13,707.11	
International Exchanges	7,921.67	
		$74,464.39
Funds for specific use other than Freer endowment—		
Investments made from gifts, from gain from sales, etc., of securities, and from savings on income	51,860.45	
Other expenditures, consisting largely of research work, travel, increase and care of special collections, etc., from income of endowment funds and cash gifts for specific use	113,498.06	
		165,358.51
Freer endowment—		
Operating expenses of gallery, salaries, purchases of art objects, field expenses, etc	287,679.63	
Investments made from gain from sale, etc., of securities and from income	957,564.76	
		1,245,244.39
Balance June 30, 1929		216,994.28
		1,702,061.57

Recapitulation of receipts, exclusive of Freer funds

Cash balance on hand June 30, 1928		$238,369.41
Receipts:		
General uses—		
For addition to endowment	$25,254.99	
Reserved as income	64,923.06	
		90,178.05
Specific uses—		
Accretions to endowment	18,065.47	
Gifts for specific use (not to be invested)	50,111.01	
Cash income from endowments for addition to endowment	6,253.39	
Cash income from endowments and from other sources for conducting researches, explorations, etc	76,172.31	
		150,602.18
Total receipts, exclusive of Freer funds		240,780.23

[4] Includes salaries of secretary and certain others.

Statement of endowment funds

	General purposes	Specific purposes other than Freer endowment	Freer endowment
Endowment, June 30, 1928	$995, 632. 81	$598, 668. 69	$4, 268, 244. 26
Increase from income, gifts, etc	21, 347. 69	8, 742. 89	5, 671. 62
Increase from gain from sales, etc	4, 443. 21	16, 366. 66	951, 893. 14
Increase from stock dividends	962. 04	2, 225. 46	10, 245. 00
Endowment, June 30, 1929	1, 022, 385. 75	626, 003. 70	5, 236, 054. 02

The following appropriations were made by Congress for the Government bureaus under the administrative charge of the Smithsonian Institution for the fiscal year 1929:

Salaries and expenses		$32, 500. 00
International Exchanges		48, 208. 00
American Ethnology		60, 300. 00
Cooperative ethnological researches		20, 000. 00
International Catalogue of Scientific Literature		7, 460. 00
Astrophysical Observatory		33, 200. 00
National Museum:		
Furniture and fixtures	$29, 560. 00	
Heating and lighting	84, 040. 00	
Preservation of collections	502, 546. 00	
Building repairs	17, 730. 00	
Safeguarding dome of rotunda, Natural History Building[5]	80, 000. 00	
Books	2, 000. 00	
Postage	450. 00	
		716, 326. 00
National Gallery of Art		31, 168. 00
National Zoological Park		182, 050. 00
National Zoological Park, building for birds		30, 000. 00
Printing and binding		95, 000. 00
Total		1, 256, 212. 00

MATTERS OF GENERAL INTEREST

FINANCIAL

Several new features have been introduced by the treasurer, Mr. N. W. Dorsey, and by the executive committee of the Board of Regents in their financial reports. Returns from royalties on the Smithsonian Scientific Series appear for the first time. Reported for six months, only, these amount to nearly $15,000. The Regents have directed that one-fourth of all sums to be received from such royalties shall be treated as income, the remainder as endowment.

[5] Work done under direction of Supervising Architect and funds disbursed by U. S. Treasury.

It was felt that the immediate application of a quarter of these funds to research would better promote progress and attract greater interest among friends of the Institution than would the assignment of the entire proceeds of royalties to the permanent endowment of the Institution.

Tables have been prepared showing the condition and objects of the many special funds and showing the increases in general and special endowment from time to time during the history of the Smithsonian. Certain funds of fairly general application had been allowed to accumulate for a good many years. The chief of the Bureau of Ethnology having reported the critical emergency to ethnology which inheres in the imminent decease of the last surviving members of certain Indian tribes, the secretary directed that of the annual income of the said funds, an amount totaling about $3,500 should be devoted for several years to collecting this vanishing knowledge.

In accord with the recommendations of the Institution's financial advisers, Messrs. Scudder, Stevens, and Clark, of New York, and with the approval of the permanent committee of the Board of Regents, a considerable part of the endowment has been held for several years in the stocks of widely diversified and well-established companies and in short-term bonds. In this way the Institution has been able to share in the prosperity of our country and has enjoyed a considerable appreciation of its funds.

Especial mention is due the cooperation of the Research Corporation of New York, whose grants of funds have helped greatly to establish the new Division of Radiation and Organisms.

GIFT OF ART COLLECTION OF JOHN GELLATLY

The most important art collection to be received by the Institution since the Freer gift came during the year from Mr. John Gellatly, of New York City. The collection, valued at several million dollars, comprises more than 100 works of American art, some choice European paintings, and large collections of glass, jewels, tapestries, oriental specimens, and other valuable material, all provided with beautiful cases. Mr. Gellatly's offer was considered by the National Gallery of Art Commission and its acceptance highly recommended to the Smithsonian Regents. The Regents acted favorably upon the recommendation, and subsequently Congress passed the following joint resolution, approved by the President on June 6, 1929:

Whereas Mr. John Gellatly has offered to the Nation his art collection for eventual permanent exhibition in the National Gallery of Art under the administration of the Smithsonian Institution; and

Whereas the National Gallery of Art Commission has recommended to the Board of Regents of the Smithsonian Institution the acceptance of this collection on account of its high merit; and

Whereas the said Board of Regents have approved in principle this recommendation: Therefore be it

Resolved by the Senate and House of Representatives of the United States of America in Congress assembled, That the Smithsonian Institution is requested to convey suitable acknowledgment to the donor, and is authorized to include in its estimates of appropriations such sums as may be needful for the preservation and maintenance of the collection.

By the terms of the deed of gift the collection is the property of the Smithsonian Institution in trust for exhibition in the National Gallery of Art. It will remain in the Heckscher Building in New York City, where it is now housed, for four years. It is hoped that by the end of that period the National Gallery of Art will have a suitable building and the collection can then be transferred to Washington.

DIVISION OF RADIATION AND ORGANISMS

In the early history of the Smithsonian Institution its operations were well rounded. The natural history sciences and the physical sciences shared nearly equally in its work. Of late years only in the Astrophysical Observatory, and to a minor extent in chemical investigations in the Department of Geology of the National Museum, have the physical sciences been represented in the Institution's researches. However, the work of the Astrophysical Observatory has developed a body of experience in the measurement of radiation and of heat, and a collection of large pieces of optical apparatus, which, combined, comprise a unique preparation for research on the relations of radiation to life.

It is therefore with unusual satisfaction that I record the establishment on May 1, 1929, of the Division of Radiation and Organisms.

The staff is at present composed of Dr. F. S. Brackett, research associate in charge; Dr. E. S. Johnston, consulting plant physiologist; Mr. L. B. Clark, research assistant; and Miss V. P. Stanley, stenographer and laboratory assistant. With these cooperate the staff of the Astrophysical Observatory. Offices have been made available by remodeling the flag tower of the Smithsonian Building and installing an elevator, and laboratories are being constructed and equipped in the basement. These include plant-growth chambers, spectrograph and photometer rooms, a physical laboratory accommodating infrared spectroscopes, a chemical laboratory, and a glass-blowing room. At the close of the year work was nearly completed on the preparation of these laboratories and general equipment and special apparatus were being arranged for.

Investigations upon living organisms will at first be confined to the growth of plants under rigidly controlled physical and chemical conditions, the control extending to soil, gases, temperature, humidity, and intensity and color of light. General biological problems will be attacked through spectroscopic investigations of the complicated molecules which are a part of living organisms; that is, a study of the radiation arising from the internal vibrations of the molecules themselves. The work will be done in close cooperation with the Fixed Nitrogen Laboratory of the Department of Agriculture, as well as with men of diverse training in the biological sciences, so that modern specialization may be taken advantage of in these studies on the border line of several sciences.

EXPLORATIONS AND FIELD WORK

The field expeditions sent out under the administration or cooperation of the Institution as an important part of its program in the increase of knowledge numbered 29 during the year. They pertained chiefly to anthropology, geology, biology, and astrophysics, and many thousands of specimens and much valuable information resulted from them. Preliminary illustrated accounts of the work appeared in the annual exploration pamphlet issued by the Institution, and brief notices of many of the expeditions will be found in the reports of certain of the bureaus under Smithsonian direction, appended hereto. The Institution is able to bear the expense of but a very small proportion of the explorations, the rest being supported by cooperative arrangements with other governmental and scientific establishments and private individuals.

The year's expeditions visited such widely scattered regions as China, Alaska, Canada, Labrador, Haiti, Cuba, Honduras, various European countries, the Anglo-Egyptian Sudan, and the Philippines, besides 15 States in this country. Among the more extended expeditions may be mentioned Dr. Paul Bartsch's molluscan work in Cuba; investigations of the ancient Eskimo culture of northwestern Alaska, by Dr. A. Hrdlička and Mr. Henry B. Collins; the joint zoological and archeological expedition of Messrs. Miller and Krieger to the Dominican Republic and Mr. Arthur J. Poole's exploration of Haitian caves; the zoological collecting of the Rev. David C. Graham and the Freer Gallery's archeological work under Mr. Carl W. Bishop in China; and the botanical explorations in Honduras by Mr. Paul C. Standley.

COOPERATIVE ETHNOLOGICAL AND ARCHEOLOGICAL INVESTIGATIONS

As stated in my last report, Congress in 1928 passed an act authorizing the appropriation of $20,000 for cooperative ethnological

and archeological investigations, the Secretary of the Smithsonian Institution being designated to pass upon the merit of the proposed work and to make available from the money so appropriated a sum equal to that provided by any State, educational institution, or scientific organization in the United States, such sum not to exceed $2,000 in any one State in any one year. The direction of the work and the division of the result thereof was also placed under the Secretary of the Smithsonian. During the past year 16 allotments for cooperative projects have been approved as follows:

1928

June 19. State archeologist of Tennessee, to conduct archeological investigations in the Great Smoky Mountains, $500.

July 16. Indiana Historical Bureau, to make an archeological survey of the southeast portion of the State of Indiana, together with the excavation of a typical mound, $900.

Nov. 12. Oklahoma Historical Society, for excavation of a group of mounds of the true Mound Builder type in the northern part of Le Flore County, Okla., $1,000.

Nov. 20. University of California, to conduct ethnological investigations among the Yuma and Kamia Indians of southern California, $200.

Nov. 20. University of California, to conduct ethnological investigations among the Yokuts and Western Mono of San Joaquin Valley and southern Sierra Nevada, $200.

Nov. 26. University of Chicago, to excavate a series of mounds near Quincy, Ill., $1,000.

Nov. 28. University of Washington, to make a study of the Lummi Indians near Bellingham, Wash., $100.

1929

Apr. 12. University of California, for an investigation of the Nisenan or Southern Maidu of north central California, $300.

Apr. 12. University of California, for an investigation of the culture of the Kawaiisu of south central California, $250.

Apr. 12. University of California, for an intensive study of the basketry art of the Indians of northwestern California, $250.

Apr. 12. University of Michigan, to conduct an archeological survey of Muskegon and Marquette River Valleys, $500.

June 12. Colorado State Historical Society, to conduct archeological reconnaissance and excavations in Montezuma County, Colo., $1,200.

June 12. Logan Museum (Beloit, Wis.), to conduct archeological excavations in supposed Arikara sites, $500.

June 12. San Diego Museum, to conduct archeological investigations and excavations in western San Diego County, Calif., $800.

June 12. Yale University, to conduct studies of Indian music, $500.

June 27. Indiana Historical Bureau, to continue archeological survey of the State of Indiana, $1,000.

PUBLICATIONS

Partly through its very extensive correspondence, but chiefly through its publications, the Institution carries on its program of diffusion of knowledge. All of its 11 distinct series are scientific in

character, except the catalogues of the National Gallery of Art. Two of its less technical publications, namely, the Smithsonian Annual Report and the annual Smithsonian Explorations and Field Work pamphlet, are intended primarily for the general reader who is interested in the progress of science. All of its publications are distributed free to a large list of libraries and scientific and educational institutions throughout the world. A limited number of copies of papers in the Miscellaneous Collections series are held for sale at cost price.

The Annual Reports of the Smithsonian Institution are perhaps its most widely known series. Printed each year as a general appendix to these reports is a selection of about 30 articles chosen from the periodical literature of the world or specially contributed to illustrate in a readable and authoritative manner the advances in all branches of science for the year. For example, in the report for 1928 the following three typical articles appear:

New Results on Cosmic Rays, by R. A. Millikan and G. H. Cameron.

The Controversy Over Human "Missing Links," by Gerrit S. Miller, jr.

Communication Among Insects, by N. E. McIndoo.

The Institution published during the past year a total of 128 volumes and pamphlets; and 197,573 copies of Smithsonian publications were distributed, including 26,709 volumes and separates of the Smithsonian Annual Reports, 31,121 volumes and separates of the Smithsonian Miscellaneous Collections, 3,773 Smithsonian Special Publications, 115,128 publications of the National Museum, and 20,112 publications of the Bureau of American Ethnology. More detailed information regarding the publications is given in the report of the editor of the Institution, Appendix 11.

SMITHSONIAN SCIENTIFIC SERIES

As a means of augmenting its income for researches and publications, the Institution entered into an agreement in 1928 with the Smithsonian Institution Series (Inc.) of New York to publish a set of 12 volumes to be known as the Smithsonian Scientific Series, under the editorship of the secretary. These volumes, prepared at the Institution, present in popular form, profusely illustrated, the scientific activities of the Smithsonian and the wealth of natural-history material in the National Museum and Zoological Park. The sale of the series is entirely in the hands of the New York publishers, the Institution appearing only in the capacity of author.

The first four volumes appeared during the year and were distributed to the subscribers to the James Smithson Memorial Edition

whose names will be found in Appendix 12. These volumes were as follows:

1. The Smithsonian Institution, by Webster Prentiss True.
2. The Sun and the Welfare of Man, by Charles Greeley Abbot.
3. Minerals from Earth and Sky. Part I, The Story of Meteorites, by George P. Merrill. Part II, Gems and Gem Minerals, by William F. Foshag.
4. The North American Indians. An account of the American Indians north of Mexico, compiled from the original sources, by Rose A. Palmer.

The remaining eight volumes are in press or well advanced in preparation and will be issued in course of the calendar year 1930.

LIBRARY

The Smithsonian library is made up of 10 divisional and 36 sectional libraries. The former include the Smithsonian deposit in the Library of Congress, which is the main library of the Institution, the Smithsonian office library, the Langley aeronautical library, and the seven libraries of the bureaus under direction of the Institution. The sectional libraries are smaller units maintained in the offices of members of the staff for use in connection with their work. The library as a whole comprises about 800,000 volumes, pamphlets, and charts. Accessions for the year included 7,244 volumes and 7,627 pamphlets and charts, a total of 14,871 items.

Three important changes took place in the library during the year: The library of the Bureau of American Ethnology, previously an independent library, was made a division of the Smithsonian library; a new divisional library was organized for the recently established Division of Radiation and Organisms of the Institution; and the technological library was made a part of the National Museum library.

The outstanding gift of the year was the Harriman Alaskan library, brought together by Dr. W. H. Dall and presented by Mrs. Edward H. Harriman. Other important gifts include 1,000 publications from Mr. Herbert A. Gill, 500 books and periodicals on photography from Mr. A. B. Stebbins, and 1,500 publications of the Philosophical Society of Washington from the society itself.

Items of notable progress in the reorganization of the library under the direction of the librarian will be found in Appendix 10.

GOVERNMENTALLY SUPPORTED BRANCHES

There have grown up under the initiative of the Smithsonian Institution and at large expense of its private funds numerous enterprises which have become public necessities. Of these, seven, by direction of Congress, are still administered by the Institution, though almost entirely supported by governmental appropriations.

These are: The National Museum, the National Gallery of Art, the Bureau of American Ethnology, the National Zoological Park, the Bureau of International Exchanges, the Astrophysical Observatory, and the Regional Bureau of the International Catalogue of Scientific Literature. Besides these the Smithsonian administers the Freer Gallery of Art, the gift of Charles L. Freer to the Institution in trust for the American people.

NATIONAL MUSEUM

Of the governmental branches of the Institution the most important is the National Museum. On the one hand its exhibitions entertain and instruct visitors, young and old, from all parts of our country and the world. On the other it is the repository of an enormous number of specimens of fauna, flora, geology, mineralogy, history, ethnology, and archeology, representing not only the United States but other regions, including the great oceans. These collections in many instances can no longer be duplicated, owing to the changed conditions now existing. They form a rich basis for research, valuable both for utilities and for pure science. The duty also devolves on us of continuing explorations and collecting, especially where the conditions tend toward the early loss of opportunities now available. Only in this way can the interests of the future be protected.

The appropriations for the maintenance of the Museum totaled $748,024, an increase of $97,064 over the preceding year. A large part of this increase was provided for much-needed adjustment in the salaries of the Museum staff, including a revision of the schedules of the various grades and a one-rate increase for employees who had attained proper efficiency ratings. Although the effect of this increase in salaries was immediately apparent in improved morale, the Museum salary rates are still below the average for similar organizations in the Government service, and it is urgently hoped that provision may be made for a further one-rate advance. The question of additions to the personnel is of growing importance, as in several divisions there are no assistants in training to carry on the work when the older men are gone, and for certain collections of scientific material there is no specialist in charge. The acute housing needs of the Museum include additional wings on the Natural History Building to relieve the present overcrowded condition and a more adequate and modern building to replace the old Arts and Industries Building, constructed nearly 50 years ago and entirely unsuited to present requirements.

The collections have been increased during the year by the addition of 545,191 specimens, by far the largest part of these coming to the department of biology. Gifts to schools numbered 3,258

specimens, and 23,326 were sent out in exchange to other organizations and individuals. Loans to scientific workers totaled 33,723 specimens.

The department of anthropology received a large collection, gathered by Mr. H. B. Collins, jr., from islands off the coast of Alaska, of ivory and bone implements illustrative of Eskimo culture from very early times to the period of Russian exploration. A series of objects representing the ethnology of the Nigerian and Gold Coast in Africa was presented by Mr. C. C. Roberts and another from the region of the Belgian Kongo was given by the Rev. Ellen I. Burk.

In biology there was received the valuable collection of mammals, birds, and insects bequeathed by the late Col. Wirt Robinson, and large series of birds and plants obtained in hitherto unrepresented areas of western China by Dr. Joseph F. Rock, presented by the National Geographic Society. Through the continued work of Dr. David C. Graham large collections of biological material from western China were received, and Mr. E. C. Leonard collected large series of plants in Haiti through the financial assistance of Dr. W. L. Abbott. The division of mammals received a complete skeleton of an adult sperm whale, the gift of Mr. Ippei Yokoyama, president of the Oriental Whaling Co. Nearly 200,000 land shells were collected in Cuba by Dr. Paul Bartsch, under the Walter Rathbone Bacon Traveling Scholarship.

In the department of geology a meteoric iron weighing 1,060 pounds, from New Mexico, was purchased through the Roebling Fund. The mineral collections were enriched under the same fund by the addition of a large mass of pegmatite from Maine, a nugget of platinum weighing 17.274 ounces from South America, and a cut gem of benitoite weighing 7.67 carats, the largest known cut stone of this material. Through the Chamberlain Fund a number of interesting specimens were added to the gem collection. Among additions to the fossil collections may be mentioned remains of dinosaurs of several species brought by Mr. C. W. Gilmore from Montana, and specimens of Pleistocene mammals collected by Doctor Gidley in Florida.

The arts and industries department received many valuable additions, including three early types of Winton automobiles, one of the engines of the Army airplane *Question Mark*, which remained in the air nearly seven days, and an exhibit illustrating the entire process of shoemaking by machinery. The most important accession in the division of history was a silk dress worn by Martha Washington, received as a permanent loan from Mrs. Morris Whitridge.

The usual large number of field expeditions were taken part in by the Museum; these will be found described briefly in the report on

the Museum, Appendix 1. Work on safeguarding the dome above the rotunda was completed on May 14, 1929, the work being performed under direction of the engineers in the office of the Supervising Architect, Treasury Department. The auditorium and lecture rooms were used during the year for 125 meetings, covering a wide range of scientific and other activities. Visitors to the Museum for the year totaled 1,929,625, a large increase over the previous year. Eight volumes and 61 smaller papers were published, and 115,128 copies of Museum publications were distributed during the year.

NATIONAL GALLERY OF ART

The outstanding event of the year was the gift by Mr. John Gellatly of his important art collection mentioned in detail elsewhere in this report. Other than this, but few accessions came to the gallery, owing to the complete exhaustion of available space and the fact that no provision has yet been made for the erection of a new building.

The eighth annual meeting of the gallery commission was held December 11, 1928. At a special meeting held in April, 1929, the commission recommended to the Smithsonian Regents the acceptance of the Gellatly collection. At this meeting also the chairman, Mr. Gari Melchers, announced that the Carnegie Corporation had granted $1,000 for the purpose of assembling the art works so far purchased under the Ranger fund for temporary exhibition in the National Gallery. It is intended to hold the exhibition during December, 1929.

Six special exhibitions were held in the gallery, including a group of four portraits by M. L. Theo Dubé; a collection of paintings of the Gothic cathedrals of France, by Pieter van Veen; an exhibit of early American miniatures, by Edward Greene Malbone; 42 water-color paintings of scenes and figure subjects in India, by William Spencer Bagdatopoulos; a collection of paintings of Arctic and Antarctic scenes and character studies by Frank Wilbert Stokes; and an exhibition of paintings and sculpture by American negro artists.

FREER GALLERY OF ART[6]

The year's additions to the collection by purchase include examples of early Persian and Egyptian bookbinding; Chinese bronzes; Syrian glass; Persian, Turkish, and Egyptian manuscripts; Chinese, Japanese, Indian, and Persian paintings; Chinese, Persian, and west Asian pottery; and Chinese silver.

---

[6] The Government's expense in connection with the Freer Gallery of Art consists mainly in the care of the building and certain other custodial matters. Other expenses are paid from the Freer endowment funds.

The total attendance for the year was 116,303, of which number 2,101 came to the offices for general information, to study the building and methods, to see objects in storage, or for other purposes. Ten classes were given instruction in the study rooms and twelve groups were given docent service in the galleries.

Gratifying progress has been made in the work of the field service. Dr. C. Li, of the field staff, was given every assistance by the Chinese Government in carrying on important archeological excavations in the Province of Honan. Political conditions in China have improved steadily during the year, and it may be confidently expected that the Freer Gallery's work in the field may now be carried on without interruption of any kind.

BUREAU OF AMERICAN ETHNOLOGY

On August 1, 1928, Mr. Matthew W. Stirling assumed the office of chief of the bureau, succeeding Dr. J. Walter Fewkes, who retired earlier in the year.

The work of the bureau for the year covered widespread ethnological and archeological investigations relating to numerous Indian tribes. Mr. Stirling completed a survey of an interesting group of mounds in the vicinity of Tampa Bay, Fla., selecting a large mound at Palma Sola as a site for later intensive excavation. Doctor Swanton continued work on the Timucua dictionary, and Doctor Michelson renewed his researches among the Algonquian tribes of Oklahoma and the Fox Indians of Iowa. Mr. Harrington completed his report on the Taos of New Mexico and studied the Karuk of California. Doctor Roberts brought to completion his archeological work along the Piedra River in Colorado, uncovering 50 houses of the prehistoric Pueblo peoples, and prepared a report covering the investigation. Later in the year he began excavations at a site in eastern Arizona, revealing eight pit houses occupied by Basket Maker III and Pueblo I peoples. Mr. Hewitt continued his ethnological work among the Iroquois, and Doctor La Flesche revised the manuscript of his Osage dictionary. Miss Densmore studied the music of various tribes in Wisconsin.

The bureau published three annual reports, with accompanying papers, and five bulletins. A total of 20,112 bureau publications were distributed during the year.

INTERNATIONAL EXCHANGES

The number of packages of publications handled during the year was 620,485, a large increase over the number handled during the previous year. The total weight of the packages was 621,373 pounds, also an increase. These totals include both the packages sent abroad and those received for distribution in this country.

The total number of sets of United States governmental documents forwarded to foreign depositories remains at 105, but those sent to Latvia and Rumania have been increased from partial to full sets, and in several countries the location of the depository has been changed. The daily issue of the Congressional Record is now exchanged with 101 foreign establishments.

NATIONAL ZOOLOGICAL PARK

The total number of animals added to the collections during the year was 479, including an unusual number of gifts of valuable specimens, while 541 were lost through death, return of animals, and exchange, leaving the number on hand at the close of the year at 2,211. These represent 579 species of mammals, birds, reptiles, and batrachians. Because of the restrictions of exhibition space, no attempt has been made to enlarge the collection for the present, effort being concentrated on selecting through exchange and purchase only choice and especially desirable species. As a result, the collection is now unusually rich in rare and interesting forms.

The most spectacular addition of the year, and in fact of many years, was N'Gi, the gorilla purchased with money remaining from the Smithsonian-Chrysler expedition funds. On the first Sunday that he was shown at the park, despite the fact that it was a cold day, over 40,000 people came to see him. For the year the attendance reached a total of 2,528,710, a considerable increase over the preceding year. This total included 497 classes of students, aggregating 30,886 individuals.

Work on the exterior of the new bird house, built last year, was completed, including the construction of outdoor cages and the laying out of an attractive approach to the building. The roofs of several of the older buildings were repaired, and many of the bridle paths in the park were altered after consultation with those interested in riding.

Congress has appropriated $220,000 for the construction of a reptile house, which for years has been badly needed. In order to insure the best and most modern building for the exhibition of reptiles and batrachians, the Smithsonian Institution from its private funds sent the director of the park and Mr. A. L. Harris, municipal architect, to Europe to study the zoological parks of foreign cities. Twenty zoos were visited, and through the courtesy of those in charge many valuable ideas were obtained which will be used in the preliminary plans for the new reptile house.

Of the several additional buildings needed for the proper development of the National Zoo the most urgent is an exhibition building for apes, lemurs, and small mammals. For the small mammals, which include some of the most interesting of all animals, there are

at present practically no suitable quarters, and the great apes, of which the park has a valuble collection, are now so housed that it is often impossible for visitors to see them. Tentative plans for a modern, hygienic building to remedy this situation have been prepared, the estimated cost being $225,000.

ASTROPHYSICAL OBSERVATORY

The Smithsonian Astrophysical Observatory, through its field stations on Table Mountain, Calif., and Mount Montezuma, Chile, and the cooperating National Geographic Society station on Mount Brukkaros, South West Africa, has continued the exact measurement of the intensity of the radiation of the sun as it is at mean solar distance outside the earth's atmosphere. The California and the Chile observations, having reached definitive status, now concur within narrow limits in their determination of the sun's variation. The Montezuma values of the solar constant are published by the Weather Bureau on the Washington daily weather map.

Further investigations have apparently confirmed three definite periodicities previously noticed in the solar variation of approximately 11, 15, and 26 months.

At the Mount Wilson, Calif., station, Doctor Abbot and Mr. Freeman repeated with richer results the bolometric determination of positions of solar and terrestrial absorption lines and bands in the infra-red solar spectrum, which formed the main subject of Volume I of the Annals of the Astrophysical Observatory. Another research carried through at Mount Wilson was the observation of the distribution of energy in the spectra of 18 stars and of the planets Mars and Jupiter, accomplished by Doctor Abbot, with the aid of Doctor Adams, of the Mount Wilson Observatory, using the 100-inch telescope and a sensitive radiometer.

Preparation of the text of Volume V of the Annals, to contain the numerous observations since 1920, was begun during the year, and it is hoped that the volume will be ready for publication in the fiscal year 1931.

INTERNATIONAL CATALOGUE OF SCIENTIFIC LITERATURE

Publication of the International Catalogue was suspended in 1922 because of lack of financial support, but the United States bureau, conforming with an agreement made with other bureaus, has continued to keep records of current scientific periodicals and to do other necessary work in order that actual indexing may be resumed when reorganization of the catalogue becomes possible. Expenses have been kept at the absolute minimum consistent with maintaining the bureau intact.

82322—30——3

The assistant in charge of the bureau has during the year drawn up a detailed plan whereby the work of the catalogue could be reorganized and publication resumed. The initial capital required under this plan would be $75,000 for equipping a printing plant and maintaining the central bureau for one year. After the first year the enterprise would again be self-supporting through the sale of the catalogue to subscribers. At the close of the past year the assistant in charge was in correspondence regarding the plan with Prof. Henry E. Armstrong, F. R. S., chairman of the executive committee, in whom the 1922 Brussels Convention vested authority to consider and propose plans for resuming publication.

NECROLOGY

ROBERT RIDGWAY

Robert Ridgway, curator of birds, died at Olney, Ill., March 25, 1929. He was born at Mount Carmel, Ill., July 2, 1850, and was early attracted to natural-history subjects. When a boy of 14 years he came to the attention of Professor Baird, who later secured for him the position of naturalist on the fortieth parallel survey under Clarence King. He went to San Francisco via Panama in May, 1867, and spent three years in the field. He prepared a report on the collections made by him, which was published in 1877. In the meantime, Professor Baird had projected a work on birds in conjunction with Dr. Thomas M. Brewer, and Mr. Ridgway was engaged to provide the technical descriptions. This work, the History of North American Birds, was published in three large volumes in 1874 and covered the land birds only. In 1884 the two volumes on water birds appeared, completing a memorable undertaking.

Mr. Ridgway was employed at intervals by the Smithsonian Institution up to 1874, when he was designated as ornithologist, a position he held under varying titles to July 1, 1880, when he became curator of birds, and continued under this title until the date of his death. He was a very busy worker, devoted to his subject, and spent little time in recreation. His first published note appeared in the American Naturalist, in 1869, and from that date to the present his communications were frequent, amounting to well over 500 titles in all, exclusive of his more pretentious works. In 1886 he published a Nomenclature of Colors which was quickly adopted by naturalists and became the standard for descriptive work, to be replaced only by the same author's Color Standards and Color Nomenclature issued in 1912. In 1887 his Manual of North American Birds made its appearance, followed by a second edition in 1896.

For many years Mr. Ridgway had been collecting material and data for a technical treatise on the birds of North and Middle Amer-

ica, a work that Professor Baird had in mind years ago, and when authorized by the late Doctor Goode to produce such a work he was well prepared. From 1901 to 1919 eight parts of this work, Bulletin No. 50 of the United States National Museum, were issued, and he was engaged on the manuscript of the ninth and tenth parts at the time of his death.

In recognition of the quality of his work he received many honors from scientific societies both at home and abroad. Some years ago he was granted the Walker Grand Prize, issued by the Boston Society of Natural History, the Daniel Giraud Elliot gold medal, and the William Brewster medal and prize. He was a member or honorary member of various ornithological societies, the Zoological Society of London, the Manchester Literary and Philosophical Society, and others.

Mr. Ridgway was keenly interested in field work, and made many trips to various parts of Illinois and Indiana. He visited Florida in three successive years (1895–1897), accompanied the Harriman Alaska expedition in 1899, and made two collecting trips to Costa Rica, 1904 and 1908.

EUGENE AMANDUS SCHWARZ

Eugene Amandus Schwarz, custodian of coleoptera in the National Museum, died October 15, 1928. He was born in Liegnitz, Silesia, April 21, 1844, and came to America in 1872, taking up work with Hagen at Cambridge, Mass. In 1874 he accompanied his friend and pupil, H. G. Hubbard, to Detroit, where they founded the Detroit Scientific Association and started an entomological museum. In this year he spent several months collecting insects in Florida, the first of a long series of collecting expeditions that continued throughout his life. In 1878 he came to the Department of Agriculture, where he remained until his death. In 1898 he was appointed custodian of coleoptera in the National Museum, and here he introduced better standards of care and arrangement. Besides the extensive collection made by Hubbard and himself he secured for the Museum many other important collections, and he started and actively promoted the formation of a collection of coleoptera larvae, which has since grown to be probably the largest in the world.

Doctor Schwarz was very modest and self-effacing, but during the last 40 years his fame as a man of great learning slowly spread among the entomologists of this country until it became generally recognized. He always willingly placed his unlimited knowledge and experience at the disposal of the younger generations. His bibliography contains nearly 400 titles, mainly on coleoptera.

HARRISON GRAY DYAR

Harrison Gray Dyar, custodian of lepidoptera in the National Museum, died January 21, 1929. Doctor Dyar was born in New York, February 14, 1866, and was educated at the Massachusetts Institute of Technology and Columbia University. He came to the Museum in 1897 and his term of service amounted, therefore, to more than 30 years. During nearly all of this time he was a volunteer and unpaid worker, but for a few years he was on the staff of the Bureau of Entomology.

Doctor Dyar was one of the authors of the large monograph of the mosquitoes of North America published nearly 20 years ago by the Carnegie Institution, and he continued from that time to be the principal specialist in the group in the western hemisphere. The monograph having been out of print for some time he completed quite recently a new work on the mosquitoes of both North and South America, which was published last year by the Carnegie Institution in one large volume. He gave much attention to the early stages of the mosquitoes, so that his classification covered these in a very unusual degree.

In 1917 Doctor Dyar gave to the Museum his entire collection of insects, numbering some 35,000 specimens. As a result of his labors the National Museum has one of the largest collections of mosquitoes in the world and probably by far the largest one in larval stages and in mounted specimens of genitalia.

JOHN DONNELL SMITH

John Donnell Smith, for many years honorary associate in botany, Smithsonian Institution, died December 2, 1928. Captain Smith was born in Baltimore June 5, 1829, and at the time of his death was the oldest living graduate of Yale University. Aside from distinguished service in the public welfare, his interest centered in the botany of Central America, in which field he was an acknowledged authority. In the course of his studies he had built up an extensive library and an herbarium of over 100,000 specimens, which were presented to the Smithsonian Institution several years ago. In the death of Captain Smith the world has lost a scientist of note and the Smithsonian Institution a distinguished friend and patron.

APPENDIX 1

REPORT ON THE UNITED STATES NATIONAL MUSEUM

SIR: I have the honor to submit the following report on the condition and operations of the United States National Museum for the fiscal year ended June 30, 1929:

The total appropriations for the maintenance of the National Museum for this period amounted to $748,024, an increase of $97,064 over the appropriations for the year 1928. Of this increase it is gratifying to record that a large part was provided for much-needed adjustment in the salaries paid to the Museum staff. This adjustment came partly through the operation of the Welch Act regulating governmental salaries in general, under which there was a revision of the schedules of the various grades, and partly through allowance by the Congress of additional funds to permit a 1-rate increase under the provisions of the reclassification act for those employees who had attained the proper efficiency ratings. An increase of $3,000 provided for additional storage facilities for the steadily increasing study collections. The addition of three employees, namely, an engineer, a fireman, and an elevator conductor, required for the adequate operation of the heating and lighting plant and for the proper maintenance of elevator service, necessitated $3,840 more. There was added also the new position of assistant curator in the division of mammals, where assistance was urgently required. An allowance of $1,200 provided for the purchase of uniforms for guards and elevator conductors on day duty in our buildings. An increase of $4,610 under the item for building repairs covered an additional painter, the purchase of further paint materials, and allotment for replacement of cement work on the private roadways leading to the east service entrance of the Natural History Building. The sum of $500 was added to the appropriation for the purchase of books for the Museum libraries and $2,500 to the allotment for printing and binding for the Museum.

In the first deficiency act for the fiscal year 1928 there was provision of $80,000 for safeguarding the dome of the rotunda of the Natural History Building, the work to be performed under the direction and supervision of the Supervising Architect, Treasury Department, and the money to be available until June 30, 1929.

The increase in salaries has been most gratifying and has brought needed relief in economic situation for many Museum employees. The effect of this betterment has been immediate in increased morale in an organization whose employees have always been constantly devoted to its best interests. To consider this matter further, it may be pointed out that the reclassification act at present calls for advance in salary until the average salaries paid under the various grades reach the average fixed by law for these grades. At the present time the majority of Museum employees stand at the second salary rate in their respective grades, permitting an advance of one more step according to the provision of the reclassification act. As the salary rates are still below the average for similar organizations in the Government service, it is urgently desired that further provision for this 1-rate advance be made. The present moneys in the various appropriations above the salary roll do not permit these advances. Should this additional amount be made available the salary status under the different appropriations will be rendered more or less stable without necessity for further considerable increases in salary allotment under present circumstances. There will remain only the need of adjustment of classification in some instances and the additions of new personnel required in many cases. It is earnestly hoped that the promotions required may be made in the fiscal year 1931.

The question of further additions to personnel remains one of importance, as there is a growing necessity for further workers both on the scientific staff and on the clerical force. Relief has been obtained in some instances, particularly in two divisions where assistants have been provided for the older men now in charge, with the intention that they may be in training to carry on when the older members are gone. Several cases of this kind remain still to be cared for, and there are in addition certain collections for which the Museum now has no specialist in charge. At the present time it is necessary to employ for short periods temporary cataloguers, typists, and laborers to assist in the regular work. These persons should be available on the permanent staff, since the work is specialized and requires considerable training for adequate and proper performance. This training it is not possible to give during a period of temporary appointment.

In the annual report for last year attention was called to the necessity for further space to house the steadily growing collections which increase annually in spite of efforts to eliminate material that is not required for permanent preservation. The whole collection forms a valuable part of the riches of our National Government—a part that will increase steadily in value because each year more and more objects become impossible to duplicate through the destruction by

our advancing civilization of an increasing number of natural forms. Proper provision must be made to secure everything of importance obtainable while there is yet opportunity.

Needs for housing in the National Museum, as outlined last year, include additional wings on the Natural History Building to provide for relief from the present congestion, which in many cases is now acute. Of equal importance and necessity is more adequate provision for the collections in arts and industries at present housed in the old National Museum Building, which when constructed in 1881 was adequate for the needs of those days, but which is not designed in a manner commensurate with present requirements. This building should be replaced by another much larger structure that will provide proper housing for the objects in this collection. These have great importance to the American Nation as a record of industrial development, commerce, and engineering in all its lines. The series of Patent Office models alone, representing the basic principles from which our important economic advances have grown, is of itself of sufficient importance to warrant the proposed building. With these, coupled with related historic objects of all kinds drawn from other sources, it results that the national collections contain materials that can not be duplicated in any other museum of the kind in the country or in the world. With provision being made for industrial museums in other sections of the country we should prepare at once for more adequate housing for the national collections of this kind in Washington.

The collections of history at present are placed in part in the Natural History Building and in part in the building given over principally to arts and industries. The historical materials concern persons and events of supreme importance to our Nation, since they treat of the very birth, growth, and expansion of our country. As such they are of absorbing interest to every patriotic American and should be displayed to the fullest advantage. At the present time the limits of space are such that many interesting objects can not be placed on public display and it is necessary at times to decline materials that should be accepted, because of lack of proper facilities for their preservation.

Preparation of plans and other necessary arrangements for housing space will require considerable time. With our need now acute the preliminaries necessary before actual construction may be begun should not be postponed. The present interest of the public demands prompt action in these matters.

The steadily growing attendance in the Museum halls is in itself sufficient indication of the interest of the American public in the

National Museum and its collections. More adequate housing facilities can not but add to this interest and will assist in making Washington even more attractive to the hundreds of thousands of our countrymen who journey each year to visit the seat of government of our great Nation.

COLLECTIONS

Additions to the collections of the National Museum during the fiscal year have reached the large total of 545,191 separate objects, by far the greater part of these coming to the department of biology. This increment, while not quite equal to that of last year, is on a parity with that received in the last few years. The collections of the National Museum are now universally recognized as of such great value and importance as to draw to them donations of the most valuable kind in the form of collections gathered under private or other auspices which it is desired to place where they will have assurance of proper care and permanent preservation. Recognition that in the National Museum there may be found these conditions is highly gratifying. Material of various kinds sent for examination and report during the year amounted to 1,314 lots, including many thousands of separate things. Gifts to schools and other educational institutions included 3,258 specimens, while in exchange with other scientific organizations and individuals there were sent out 23,326 specimens, these being duplicate materials for which others were received in return. Loans of all kinds to scientific workers outside of Washington included 33,723 specimens, many of them highly valuable.

Following is a digest of the more important accessions for the year in the various departments and divisions of the Museum.

Anthropology.—An expedition under direction of Henry B. Collins, jr., to St. Lawrence Island in Bering Sea, including work on the islet of Punuk, brought the largest selection of historical-archeological materials ever obtained by the Museum in one season from the Bering Sea area. In it are found many hundreds of ivory and bone implements illustrative of the culture of the Eskimo from very early times down to the period of Russian exploration. The carvings shown are of three distinct types, indicating as many cultural stages in the development of the people who made them. The entire collection is one almost without parallel in our history and will be of great importance in elucidating the period of habitation at the village sites represented.

Among other valuable collections there has come a series representing the ethnology of the Nigerian and Gold Coast in Africa, the gift of C. C. Roberts. A further collection from Africa of considerable

importance in ethnology is one from the region of the Belgian Congo received as a gift from the Rev. Ellen I. Burk.

There was received also a number of miscellaneous materials secured by Dr. David C. Graham in connection with his work in western China, principally in the Province of Szechwan.

An exchange of specimens with A. S. Kenyon, of Melbourne, Australia, brought a miscellaneous collection of decorative art work on wood, stone, and shell, and in basketry, as well as stone and wooden message sticks and an assortment of throwing sticks, including decorated boomerangs.

Archeological materials include an old type of reed basket from a rock shelter in Russell County, Ky., secured by purchase; flint and stone implements and bone and copper beads presented by Mr. Charles Beckman, from various sites along the Columbia River in Washington; and a series of stone implements collected by Dr. Walter Hough, head curator, in the vicinity of Abilene, Tex. Among Old World specimens there may be mentioned a series of nearly 500 that come from the work of Dr. George Grant MacCurdy, director of the American School of Prehistoric Research, from localities in Dordogne, France, received as a loan from the Archæological Society of Washington. Skulls and skeletons of ancient Eskimo from the Collins collection on St. Lawrence Island form one of the most important additions to the division of physical anthropology in this department. There were received also 10 masks taken from living Labrador Eskimo, obtained in exchange from Prof. V. Suk, of the University of Brno, Moravia.

Biology.—Noteworthy among receipts in this department have been the highly valuable collections of mammals, birds, and insects left to the Museum by bequest by the late Col. Wirt Robinson, long a valued contributor to the Institution. There may be mentioned also large collections of birds and plants obtained by Dr. Joseph F. Rock in western China from areas previously unrepresented in our halls, which were received as a gift from the National Geographic Society, under whose auspices the field work was performed.

Excellent collections from western China in many branches of biology, principally in birds, mammals, insects, crustaceans, and fishes, were obtained through the continued efforts of Dr. David C. Graham, who has long been a resident in the Province of Szechwan, and who has been most assiduous in obtaining representatives of the fauna in that area for the National Museum. From farther south, in Siam, there were obtained large and valuable series of mammals, birds, reptiles, insects, mollusks, and miscellaneous invertebrates collected through the efforts of Dr. Hugh M. Smith, honorary curator in zoology on the staff of the Smithsonian Institution, who is now

fisheries advisor to the King of Siam. The material obtained this year, supplementing that mentioned in previous reports, has included a number of forms, particularly in birds, that have been new to science.

Collections from Haiti, through the financial assistance of Dr. W. L. Abbott, have included large series of plants from the northwestern part of that country secured by E. C. Leonard, of the division of plants, in the prosecution of his field studies for a flora of the island. At the same time there were obtained further collections of bones of extinct animals from cave deposits through the field researches of A. J. Poole and W. M. Perrygo, of the Museum staff, who, in addition, collected series of birds and reptiles to supplement earlier collections in these same fields. Doctor Abbott further presented an excellent collection of Siamese mammals which were obtained during an expedition under his auspices.

One of the most valuable accessions in the division of mammals has been the complete skeleton of an adult sperm whale, presented by Mr. Ippei Yokoyama, president of the Oriental Whaling Co., through the interest of Prof. Chiyomatsu Ishikawa. It was brought to this country under the direction of the Japanese ambassador, the Hon. Katsuji Debuchi. Another accession in this division consisted of 27 mammal skulls from India, received as a gift from Gen. William Mitchell.

Under the Bradshaw Hall Swales fund the division of birds secured by purchase 45 specimens of species not previously represented in its series. Through the Smithsonian Institution there were obtained by purchase from J. A. Reis, jr., 177 skeletons of birds from Cameroon, numbering about 116 species, a valuable addition to the skeleton collection. Eggs of the California condor, a bird nearly extinct in the wild state, were obtained from the National Zoological Park.

Dr. Homer W. Smith, of New York City, presented specimens of the lung fishes of Africa.

One of the important accessions in the division of insects has been a collection of Lepidoptera received as a permanent deposit from the Brooklyn Museum, which included more than 66,000 specimens, with types of about 650 species.

The division of mollusks obtained about 200,000 land shells from Cuba, collected by Dr. Paul Bartsch, traveling under the Walter Rathbone Bacon Traveling Scholarship.

Geology.—The meteorite collection has secured through purchase under the Roebling fund an iron weighing 1,060 pounds from the Zuñi Mountains south of Grant, N. Mex. A smaller specimen of the same type, also purchased from the Roebling fund, was secured from Red River County, Tex., while a third came from near Lawrence, Kans.

Through the income of the Roebling fund the mineral collections have grown in a highly gratifying manner during the past fiscal year. A striking addition to the exhibit series is a large mass of pegmatite from Newry, Me. Another purchase of importance was that of a nugget of platinum weighing 17.274 ounces from South America. There may be mentioned further a cut gem of benitoite, weighing 7.67 carats, being the largest known cut stone of this mineral.

Through the Chamberlain fund there have come to the gem collection a carved statuette of rose quartz, a Chinese carving of tourmaline, a yellow topaz weighing 34 carats, a cameo of Hungarian opal, and a cut gem of pollucite.

Fossil materials include large lots of invertebrates obtained by exchange, gift, and collection, among them three rare star fishes and five crinoids from the Ordovician of Minnesota, purchased under the Springer fund. From field work by Mr. C. W. Gilmore in Montana there have come remains of dinosaurs of several species previously not in the Museum, and there may be mentioned also specimens of Pleistocene mammals collected by Doctor Gidley in Florida.

Arts and industries.—Valuable additions in this department have included three early types of Winton automobiles; one of the engines of the Army aircraft *Question Mark* used during an endurance test that continued nearly seven days; and a working model of the telephone transmitter and receiver obtained from the American Telephone & Telegraph Co.

A horse-drawn brougham, a fine example of the work of the famous nineteenth-century coach builder, Healey, of New York, was presented by Mr. William P. Eno, an interesting object in this day of motor transport.

An exhibition now being organized dealing with mechanical power has received a number of accessions, among them an electrically operated model of the original Pearl Street electric power station in New York City.

In the division of textiles a number of manufacturers have continued their cooperation through the contribution of exhibition material of modern textiles. An interesting exhibit received from the United Shoe Machinery Corporation illustrates the entire range of shoemaking by machinery.

An important addition to the section of photography was the first portrait taken on an autochrome plate by the inventor of the process, Antoine Lumière. Four photographs donated by Philip P. Quayle, of the Peters Cartridge Co., of bullets fired from a gun, record the bullet in silhouette, and a representation of the sound waves produced.

History.—The most important accession in this division was a silk dress worn by Mrs. Martha Washington, received as a permanent loan from Mrs. Morris Whitridge in memory of her sister, Miss Sallie Pinkerton Mackenzie. This has been installed in its proper place in the series of dresses of the mistresses of the White House shown in the costumes collection.

For the military collections there was obtained a series of uniforms owned and used by Maj. Gen. Leonard Wood, United States Army, from 1898 to 1921, presented by Mrs. Leonard Wood. The naval collections received a model of the schooner *Hannah*, of Marblehead, the first armed vessel to sail at public expense during the War of the Revolution.

Through the cooperation of the American Numismatic Association a number of valuable additions were made as loans to the numismatic collection. These included 133 specimens from many countries. The Bureau of the Mint, United States Treasury Department, continued its cooperation in building up this collection by the transfer of 85 coins struck by the United States Mint in 1928, as well as other specimens.

The philatelic collection was increased by 5,775 specimens, of which the greater part was received from the International Bureau of the Universal Postal Union at Berne, Switzerland, through the Post Office Department.

REORGANIZATION OF THE MILITARY EXHIBITS

The military exhibits concerned with the World War, assembled after the close of that conflict, through necessity of available space were installed originally in widely separated halls—in part in the Natural History Building and in part in the Arts and Industries Building on the opposite side of the Smithsonian Park. These exhibits, whose assembling was possible only through the interested cooperation of the War Department, for years have been an attractive subject to large numbers of our visitors. For sometime past ways and means for a better coordinated installation of this material have been under consideration. The War Department, taking renewed helpful interest in these exhibits, in 1928 appointed Maj. Louis A. O'Donnell, United States Army, to cooperate with the Museum authorities in the preparation of plans for their better display. On September 28, 1928, the War Department further announced an advisory committee to assist Major O'Donnell by consultation and cooperation as follows: Lieut. Col. Harry B. Jordan, General Staff Corps; Lieut. Col. Paul D. Bunker, Coast Artillery Corps; Maj. John W. Lang, Infantry; Maj. Marion O. French, General Staff Corps; and Capt. Edwin M. Scott, Quartermaster Corps. Through plans de-

vised by Major O'Donnell and approved by the assistant secretary, certain material was returned to the War Department as no longer needed for exhibition, an artillery park was arranged in the open on ground belonging to the Smithsonian Institution, the military collections were concentrated in one connected series in the Arts and Industries Building with the majority of the other historical collections, and definite arrangements were made for building up all the military collections along agreed lines.

In connection with the assembling of these military exhibits in the Arts and Industries Building there was required reorganization of part of the display in the divisions of mineral and mechanical technology and the transfer to the Natural History Building of the lace collections. All this has been accomplished and installation made of a considerable part of the military material. Work on the rest is progressing and will be continued along the plans definitely outlined. A part of the contemplated display will necessitate assistance in the way of additional funds, which it is hoped may be provided without too great delay.

The actual process of transfering the military collections from one building to the other began about April 1, 1929, and was a task of considerable magnitude, as it necessitated the transfer of materials covering approximately 22,000 square feet of floor space. The greater part of the work was accomplished by the staff of the division of history with the Museum labor force. The War Department cooperated measurably by the detail of five enlisted men and a truck to aid in the transfer.

This brief review of what has been accomplished will serve as partial acknowledgment of the great assistance rendered by Major O'Donnell during his connection with the Museum. On June 15 Major O'Donnell was transferred to other duties and was succeeded by Lieut. Col. Arthur Hixson, United States Army, as representative of the War Department.

EXPLORATION AND FIELD WORK

Various researches in the field have been carried on under the different departments of the Museum, principally through funds provided by the Smithsonian Institution through its private income or through the contributions of friends interested in certain projects. Limited assistance in a few instances has been given from the annual appropriation for the National Museum but this aid has comprised only a small part of the total amounts utilized, by far the greater part of which have been obtained from other sources. Additional money for such investigations is an urgent need that should be given attention. Comparatively small sums are sufficient for most of the Mu-

seum's projects, so that much good may be accomplished with slight outlay. A brief account of field activities of the present year follows:

During the spring of 1929 Dr. Walter Hough carried on archeological studies in west central Texas with a view to extending the known Pueblo or pre-Pueblo culture areas. In the same region he uncovered evidence relative to aboriginal man's early history.

From January to May, 1929, through the interest of Dr. W. L. Abbott, Herbert W. Krieger continued archeological investigations in the northern part of the Dominican Republic. The immediate culture problem that occupied his attention was to determine whether the area anciently occupied by the Ciguayan Indians of Samaná extended as far west as the valley of the Rio Yaque del Norte. A second problem was the attempt to extend the area known to have been anciently occupied by the pre-Ciguayan cave dwellers of the northern Dominican Republic. Results appear to indicate that the pre-Ciguayans had occupied the entire island, but that the Ciguayan Indians never reached as far west as the Yaque River. The work included further reconnaissance along the north shore of the Samaná Peninsula and the collection of biological material from former Indian village sites for the department of biology.

Henry B. Collins, jr., was in the field from July to October, 1928, engaged in investigations of the ancient Bering Sea culture on the islands of Punuk and St. Lawrence, with the aim of tracing early chapters in the history of western Eskimo culture. Material collected shows that there are three stages through which the art of St. Lawrence Island may be traced. An earlier stage, found only on the northern and western parts of the island on deeply patinated objects, consists of gracefully delineated straight and curved lines; an intermediate stage is simpler in design; while the third, the well-known modern and simplified art, is found at all recent sites. At Cape Prince of Wales nothing of any real antiquity was found. Results generally suggest a direct Asiatic source rather than a local cultural development for the well-known Eskimo arts. In May, 1929, Mr. Collins again left for field work to continue through the summer in the Bering Sea region. Dr. Aleš Hrdlička also proceeded to Alaska to continue his studies on early Eskimo anthropology.

Mr. Neil M. Judd was in Arizona during the summer of 1929, engaged in preparation of reports covering the 1920–1927 Pueblo Bonito explorations of the National Geographic Society, and supervising the society's 1929 beam expedition. This latter had for its object the collection of timbers from pre-Spanish Pueblo villages that will aid in completing a tree-ring chronology by means of which it is believed that absolute dates may be determined for many of our southwestern ruins.

At the end of May, 1928, Paul Bartsch, curator of mollusks, traveling under the Walter Rathbone Bacon Scholarship, began the faunal study of certain groups of land and fresh-water mollusks of the West Indies, the work for that season being prosecuted in Cuba, where he was assisted materially by Dr. Carlos de la Torre, president emeritus of the University of Habana. During four months Doctor Bartsch covered thoroughly all of the Provinces of Cuba, except that of Oriente, collecting over a quarter of a million specimens of mollusks, including large numbers of new races and species from places hitherto unexplored. The rainy season was chosen for this field work in spite of its discomforts, for it is at this time that land mollusks are most active. The collections obtained will yield much information bearing on problems of distribution, both present and past, and will throw light on the derivation of the molluscan fauna of the Antilles. Incidentally, Doctor Bartsch secured for the Museum important collections of birds, insects, batrachians, mammals, and crustacea.

Through the interest of Dr. W. L. Abbott, A. J. Poole, aid in the division of mammals, and W. M. Perrygo, of the taxidermist force, traveled in Haiti for a period of about four months, working the caves of Haiti proper and those of the island of Gonave for extinct animal bones. In addition to cavern exploration an important part of the work was the collection of birds to supplement distributional data already available, and there were obtained also mammals, mostly bats, as well as fishes, reptiles, marine invertebrates, mollusks, insects, and miscellaneous ethnological and anthropological materials.

One of the important expeditions undertaken during the year by friends of the Museum was that of the auxiliary yacht *Mary Pinchot* to the South Seas under the leadership of the Hon. Gifford Pinchot. The vessel left New York City in April for a cruise of about 10 months, with Dr. A. K. Fisher, of the Biological Survey, as naturalist, to obtain material desired for the National Museum. In the collections made in the first few weeks there have been received a skull of the little-known long-beaked porpoise *Prodelphinus plagiodon* and 10 forms of birds new to the Museum collections. Further shipments of important material are expected as the cruise continues.

Dr. Joseph F. Rock, traveling under the auspices of the National Geographic Society, visited the Kingdom of Muli, or Mili, in southwestern Szechwan, China, as well as adjacent parts of the Province of Yunnan, exploring also to the northwest of Muli in the hitherto unvisited snow range of Konka Risonquemba, rising to a height of 25,000 feet, and mountains to the east and northeast. From this work there have been obtained important collections of birds and plants, the specimens coming to the National Museum through the gift of the National Geographic Society.

Dr. Hugh M. Smith, in the course of fisheries investigations in Siam, visited the northern part of that country in November and December of 1928 and made hurried collections on Doi Angka and Doi Sutep, two previously unexplored peaks of the Khun Tan Mountains. Material secured has been of particular interest and has resulted in the discovery of new and rare species, among them seven new forms of birds.

Dr. David C. Graham continued work in the vicinity of Suifu, in the Province of Szechwan, China, and in July, 1928, set out on a journey to Ningyuenfu, by way of Yachow, spending about two months on the trip. Though bandits threatened at most of the interesting points, many valuable specimens were obtained.

During brief field investigations into the hosts of certain parasites in Virginia and North Carolina, Dr. H. E. Ewing, of the Bureau of Entomology, was accompanied by C. S. East, of the preparator staff, who collected a small series of birds for skeletons.

Dr. J. M. Aldrich, of the division of insects, began work in May, 1929, on type specimens of diptera in the British Museum, and later did some collecting of northern insects, principally diptera, in Norway and Sweden.

Dr. Waldo L. Schmitt and C. R. Shoemaker, in the course of an examination of the crustacean fauna of the region about the United States Bureau of Fisheries station at Beaufort, N. C., secured more than 1,300 specimens of marine invertebrates. Mr. J. O. Maloney, by invitation of Mr. Copley Amory, was detailed for part of the summer of 1928 to proceed to Canada in continuation of the biological survey of Mr. Amory's estate on the north shore of the Gulf of St. Lawrence, near the Matamek River. Doctor Bartsch visited the Marine Biological Laboratory at the Tortugas, Fla., from August 17 to August 30, 1928, in connection with work on the crossbreeding of Cerions, an investigation carried on in cooperation with the Carnegie Institution of Washington. While at the Tortugas Doctor Bartsch spent a day under water with the diving hood and the undersea camera going over fields photographed formerly in order to have a continuous record of life on the reefs.

From December, 1928, to the latter part of May, 1929, Mr. E. C. Leonard was engaged in botanical field work in northwestern Haiti, through the generous support of Dr. W. L. Abbott. Large collections (nearly 15,000 specimens) were obtained, which will be of very material assistance in making known the flora of Hispaniola, a project upon which Mr. Leonard has been engaged for several years. During the last three months of the fiscal year Mr. E. P. Killip, accompanied by Mr. A. E. Smith and Mr. W. J. Dennis, honorary collaborators, has prosecuted botanical explorations in eastern Peru

and adjacent regions. Reports from the field indicate that a large amount of herbarium material is being obtained that will be exceedingly valuable in current studies of the flora of western South America.

In July and August, 1928, Dr. A. S. Hitchcock, custodian of grasses, visited Newfoundland and Labrador for the purpose of studying and collecting grasses. A large illustrative series of specimens and much useful information regarding the range of species in these little-explored regions were obtained. Mr. Jason R. Swallen, assistant in the grass herbarium, spent the summer of 1928 in field work in the southwestern United States. Many of the rarer grasses were collected, as well as other material relating to current studies.

Dr. George P. Merrill, head curator of the Department of Geology, was detailed in September, 1928, to visit various mineral localities in the New England States. He first worked at the pegmatite deposits at Newry, Me., where the fine block of material mentioned elsewhere in this report was obtained. The historically interesting gem locality at Paris Hill was next given attention; then various localities in New Hampshire, all of exceptional interest. Following this, the feldspar prospects at Bellows Falls, Vt., were examined. The acquisition of the feldspar vein at Newry, Me., was considered to have more than compensated for the trip.

The explorations of Dr. W. F. Foshag were still under way at the close of the year. He reports interesting collections, particularly some borate minerals from various localities in southern California and Nevada. A part of this material has reached the Museum, but the recording will go over until the entire collection is received.

Messrs. James Benn and B. O. Reberholt were on several occasions detailed to collect geological specimens in adjacent localities in Maryland and Virginia where desirable materials could be obtained.

Stratigraphic studies of the Cambrian as developed in the larger mountain range of Wyoming were the main object of an expedition in 1928 by C. E. Resser. Nearly three months were spent in this investigation, in the course of which several mountain ranges were explored. Collections of fossils were limited, the rocks in many cases being of such shallow-water origin that the fossils have been destroyed. Much valuable information relating to stratigraphy was obtained.

Since the field exploration undertaken by C. W. Gilmore and his party in the Two Medicine formation in Montana extended well into the present year, but brief mention was made of it in last year's report. The expedition, which was in the field from May 12 to July 15, 1928, covered the Bad Land areas along the Milk and Two Medicine Rivers, on the Blackfeet Indian Reservation. Considerable

82322—30——4

success attended the work, the collections being sufficient in scope to be fairly representative of the fauna of the formation. The material as a whole is a most important addition to our series, in which practically all of the forms found were previously unrepresented. Scientifically it will be of interest, not only for the new species found, but for its decided contribution to the meager knowledge of the fauna of the formation, placing this on a basis that will permit of its comprehensive comparison with other Upper Cretaceous formations of contiguous areas.

Upon completion of the above work Mr. Gilmore visited the Bear Creek Coal Field in southern Montana for the purpose of securing some of the Paleocene mammal remains occurring in the Eagle Mine at that place. Lack of time prevented search being made for these minute fossils on the ground, but 400 pounds of the fossil-bearing matrix were boxed and shipped to the Museum.

In the early spring of 1929 work was again taken up at Melbourne, Fla., by Dr. J. W. Gidley, in continuation of the project relative to the presence of early man in Florida. About six weeks were spent in this work, for which generous financial assistance was furnished by Mr. Childs Frick. Again important evidence was gathered indicating the presence of man in Florida contemporaneous with an extinct fauna of the Pleistocene, while the mammal remains obtained will be useful in determining the exact phase of the Pleistocene represented—a still unsettled part of the general problem under investigation. In this connection it may be mentioned that assistance is being rendered by Dr. Thomas Barbour, of the Museum of Comparative Zoölogy, in continuing collecting activities in this area. The material thus obtained is being placed at the disposal of Doctor Gidley for study.

Almost at the end of the fiscal year Doctor Gidley was detailed to visit fossil-bearing beds discovered by a United States Geological Survey party at points in Idaho. Since operations had hardly begun at the close of the year, a statement regarding them will go over until next year.

In cooperation with the Peabody Museum of Yale University, Mr. N. H. Boss was detailed late in March, 1929, to engage in further exploration of a cave in New Mexico where a giant ground sloth was found last year, as well as to search other similar caves in the region. Following these operations, Mr. Boss joined Mr. Gilmore in an expedition to the San Juan Basin, N. Mex., to collect dinosaur and other vertebrate remains. As this work is expected to continue into the next fiscal year, no detailed report on either expedition will be given at this time.

Mr. Remington Kellogg and Norman H. Boss continued explorations of the Miocene along Chesapeake Bay from time to time. At little expense to the Museum, various fossil cetacean remains were added to the collection.

BUILDINGS AND EQUIPMENT

Usual repairs have been required to keep the buildings housing the national collections in proper condition during the year. In the Natural History Building exterior woodwork in the east court was painted; the walls and ceilings in 24 rooms on the ground and third floors were repainted, a necessary renovation that has been postponed for years and now must be completed in order to properly protect the surfaces in question. A section of concrete roadway opposite the east wing was renewed and temporary repair work was done on the roadways of the north entrance and on the west side of the building. The need for planting shrubbery to relieve the barrenness of the approach to the north entrance of this building has long been felt, so that it is pleasant to report that in the fall of 1928, through cooperation of the Office of Public Buildings and Public Parks, two beds of evergreens were planted, one on either side of the drive, greatly improving the appearance of this side of the building.

Work on safeguarding the dome above the rotunda began on September 12, 1928, and was finally completed on May 14, 1929, the work being performed under the efficient direction of the engineers in the Office of the Supervising Architect of the Treasury Department. Two great bands of steel were placed around the four huge piers that support the dome, one at the level of the floor of the attic and one near the tops of the piers and ceiling above. Between them steel beams were installed extending vertically from band to band behind the piers, with a series of screw jacks between the beams and the piers proper. Tension was placed on these jacks in such a way as to bring even strain all around, holding the piers from any possibility of spreading at the top. The delicate operation of adjusting the screw jacks, which required nearly three weeks for completion, was performed with the cooperation of a corps of engineers from the Bureau of Standards. Work of cleaning the stone surfaces in the rotunda and the painting necessary following the work outlined above was still in progress at the close of the fiscal year. The rotunda has been closed to the public since December 1, 1927, but will be opened early in the next fiscal year. In the Arts and Industries Building the café at the west entrance was remodeled, walls and ceilings in various rooms were painted, and necessary refinishing on exterior surfaces was carried on so far as was practicable.

In the herbarium hall in the Smithsonian Building cork carpet was laid on the floors, and exposed floors were painted, together with the walls and ceilings in various other rooms. An old stone walk on the south side of the building in bad condition was replaced by concrete. Grills were installed in window openings on the north and south sides in the new gallery of the herbarium hall.

The roof of the aircraft building was painted, as well as the exterior of the south shed.

The power plant was in operation from September 30, 1928, until May 28, 1929. The consumption of coal was 3,361 tons, an amount slightly less than that used in 1928. The average cost of coal was $5.36 per ton, somewhat less than that for last year. The Steamboat Inspection Service of the United States examined the boilers during the summer and reported them in good condition. The elevators have been regularly inspected by the District of Columbia inspector. The total electric current produced amounted to 648,863 kilowatt-hours, manufactured at a cost of 1.89 cents per kilowatt-hour, including interest on the plant, depreciation, repair, and material. The amount of electric current produced represents approximately an increase of 45,000 kilowatt-hours over any previous year. Demands for electric current are steadily increasing and further provision is required to be made before long for this current since our plant is now practically at the maximum peak of production. The ice plant manufactured 409 tons of ice at an average cost of $1.80 per ton, which is at a cost considerably less than for the past year due to the fact that there has been very little need for repairs.

During the year 30 exhibition cases and bases, 179 pieces of storage, laboratory and other furniture, and 1,476 drawers of various kinds were added, practically all of these being manufactured in our shops.

MEETINGS AND RECEPTIONS

The lecture rooms and auditorium of the National Museum during the present year were used for 125 meetings, covering a wide range of activities. Government agencies that utilized these facilities for hearings, meetings, lectures, and other special occasions included the Forest Service, the Bureau of Fisheries, the Geological Survey, the Public Health Service, and the Extension Service of the United States Department of Agriculture. The Forest Service arranged a series of addresses during the year on various matters connected with their work.

Scientific societies that met regularly in the auditorium or small lecture room included the Entomological Society of Washington, the Society for Philosophical Inquiry, the Anthropological Society of Washington, the American Horticultural Society, and the Hel-

minthological Society. Meetings were held also by the Washington Society of Engineers, the Wild Flower Preservation Society, the Potomac Garden Club, the Biological Society of Washington, the Botanical Society of Washington, the Aero Club of Washington, and the Vivarium Society. The National Association of Retired Federal Employees held regular meetings through the year, as did various groups of Boy Scouts for special addresses.

On February 22 there was a patriotic meeting under the auspices of the Masonic Clubs of the District of Columbia, addressed by Congressman C. A. Woodrum, of Virginia, on George Washington, with music furnished by the Masonic band. Groups of pupils from the public schools, Divisions I to IX, were addressed on May 28 by Dr. H. A. Smith, of the Department of Agriculture, on the protection of forests. On May 29 the Veterans of Foreign Wars of the United States, Federal Post No. 824, United States Department of Agriculture, held memorial services in the auditorium. Groups of students from Howard University were convened for special addresses on medical subjects on several occasions.

The biennial conference of the Division of Scientific Inquiry of the Bureau of Fisheries of the United States Department of Commerce took place from January 2 to 5, inclusive. The fiftieth anniversary celebration of the Geological Survey, United States Department of the Interior, was held on March 21.

The sixth National Oratorical Contest took place on April 25; and the fifth annual National Spelling Bee on May 21, the first prize being won by Miss Virginia Hogan, representing the Omaha World Herald. The Public Health Service, United States Treasury Department, held the twenty-seventh annual conference of State and Territorial health officers on June 3–4.

Boy scout executives of the scout councils held their third regional scout seminar on October 22–23. The third regional scout executive seminar of the Boy Scouts of America came on January 14. On January 30 the Early Birds, an organization interested in aeronautics, convened for an illustrated lecture.

A memorial meeting was held October 16 to commemorate the services to science of the late Dr. Eugene A. Schwarz. A memorial meeting came also on March 26 in commemoration of the life and work of the late Dr. Robert Ridgway, curator of birds in the United States National Museum.

An exhibit of the work of students in the department of architecture of George Washington University was held from April 21 to May 6. From May 15 to 27 there was displayed an exhibition by negro artists, assembled under the auspices of the Harmon Foundation and shown under the patronage of the committee on race relations of the Washington Federation of Churches.

MISCELLANEOUS

The exhibition halls of the National Museum were open during the year on week days from 9 a. m. to 4.30 p. m., and in addition the Natural History Building, the Arts and Industries Building, and the Smithsonian Building were opened Sunday afternoon from 1.30 to 4.30. All buildings were closed on the day before Christmas, Christmas Day, New Year's Day, and Inauguration Day. On Saturday, March 2, by special request of the committee in charge of inaugural arrangements, all buildings were held open until 5 p. m. to allow persons assembled for the inaugural ceremonies a better opportunity to view the exhibits. The flags on all buildings were flown at half-mast on March 26, 1929, out of respect to the late Marshal Foch, and on Memorial Day, May 30, from 8.30 a. m. until noon.

Visitors to the Museum during the year totaled 1,929,625 persons, an increase of more than half a million over the previous year, an indication of the increasing interest of all Americans in the Capital City, and of the attractions found in the exhibitions of the National Museum by the traveling public. Attendance in the several buildings of the National Museum was recorded as follows: Smithsonian Institution, 277,295; Arts and Industries, 868,952; Natural History, 650,815; Aircraft, 132,563. The average daily attendance for week days was 5,175 and for Sunday 6,330. The latter figure is a definite indication of the public desire for the opening of our exhibits on Sunday afternoons.

During the year the Museum published eight separate volumes and 61 miscellaneous papers, while the distribution of literature amounted to 115,128 copies of its various books and pamphlets. Additions to the Museum library included 2,247 volumes and 748 pamphlets obtained partly by exchange, partly by donation, and in small part by purchase from the modest sums available for that purpose. The library of the National Museum, as separate from that of the Smithsonian Institution proper, has now 74,562 volumes and 107,629 pamphlets. Though many of the accessions for the present year, as usual, came through exchanges of publications, there may be noted the gift of 1,000 volumes, pamphlets, and manuscripts of a miscellaneous character from Mr. Herbert A. Gill, of Washington, D. C., these pertaining in large part to the work of the late Dr. Theodore Gill, at one time librarian and associate in zoology of the Smithsonian Institution. Five hundred books and periodicals on photography, both American and British, some of them old and rare, came from Mr. A. B. Stebbins, of Canisteo, N. Y. The first four volumes of the Smithsonian Scientific Series, Patrons' edition, were presented by the Smithsonian Institution. Thirty publications were given by the American Association for the Advancement of Science,

The Museum maintains 36 sectional libraries in connection with its various scientific divisions. The library during the year made substantial progress in organization and increased efficiency along the lines of a program of development initiated five years ago.

Dr. J. A. Stevenson, of the Bureau of Plant Industry, United States Department of Agriculture, was given honorary appointment as custodian of the C. G. Lloyd mycological collection. Mr. Albert C. Smith and Mr. W. T. Dennis, who accompanied Mr. E. P. Killip on a botanical expedition to Peru, were given honorary appointments as collaborators in the division of plants. In the division of insects the interest and valuable aid of Mr. J. T. Barnes were recognized by his appointment to the honorary position of collaborator in the section of lepidoptera.

Mr. Conrad V. Morton and Mr. Egbert H. Walker were appointed aids in the division of plants. Dr. Remington Kellogg was made assistant curator in the division of mammals by transfer from the Biological Survey, United States Department of Agriculture, this position being one newly established this year. Mr. Frank A. Taylor, in the division of mineral and mechanical technology, was advanced from aid to assistant curator. Miss Ethel A. L. Lacy was appointed librarian in immediate charge of the accessions department of the library. Mr. W. L. Brown was advanced to the position of chief taxidermist, with general oversight of the work of the taxidermy shop.

Two employees left the service through the operation of the retirement act—William H. Kimball, finance clerk, after a total Government service of about 46 years, nearly 45 of which were in the National Museum, and Robert Stokes, laborer, on June 11, 1929, after a service of 28 years.

The Museum lost through death during the year six of its active workers and four members of its honorary scientific staff. Dr. Robert Ridgway, curator of birds, died March 25, 1929. Capt. John Donnell Smith, associate in botany, died on December 2, 1928. Dr. E. A. Schwarz, custodian of coleoptera, died on October 15, 1928. Dr. Harrison G. Dyar, custodian of lepidoptera, died January 21, 1929. Mr. H. K. Harring, custodian of rotatoria, died on December 19, 1928. Other losses by death included Mr. Charles E. Mirguet, taxidermist, on February 20, 1929; Mrs. E. Bennett Decker, clerk-illustrator, August 29, 1929; Eustance S. Brannon, watchman, on September 30, 1928; Frank Smith, laborer, on November 16, 1928; and William T. Murray, laborer, on June 9, 1929.

Respectfully submitted.

Alexander Wetmore,
Assistant Secretary.

Dr. Charles G. Abbot,
Secretary, Smithsonian Institution.

APPENDIX 2

REPORT ON THE NATIONAL GALLERY OF ART

SIR: I have the honor to submit herewith a report on the activities of the National Gallery of Art for the fiscal year ending June 30, 1929.

The year is made notable by the gift of an important collection of art works by Mr. John Gellatly, of New York. Through the instrumentality of Mr. Gari Melchers, chairman of the Gallery Commission, the donor indicated his desire, certain conditions being complied with, to present to the Nation for permanent assignment to the National Gallery of Art his collection of art works, comprising more than 100 choice examples of American painting in oil and water colors, large collections of jewelry, tapestries, glassware, and other art works, having an estimated value of several millions of dollars. After a preliminary hearing before the executive committee of the Board of Regents of the Institution, Mr. Frederic A. Delano, Hon. Reed Smoot, and Dr. John C. Merriam, a special meeting of the gallery commission was called April 13, 1929, to consider the offer. After hearing in some detail of the collection offered, of the conditions imposed by the donor, and the responsibilities necessarily assumed by the Institution and the Nation, acceptance was recommended to the Board of Regents. Subsequently the Congress passed a joint resolution which was approved by the President, June 6, 1929, authorizing the Institution to convey appropriate acknowledgments to Mr. Gellatly and to include in its estimates sums necessary for the accommodation and maintenance of the collection. The collection is at present installed in the Heckscher Building in New York City, where it is to remain for four years. A portfolio of 45 plates illustrating the collection was subsequently presented by Mr. Gellatly to the Institution and assigned by Secretary Abbot to the care of the National Gallery.

THE GALLERY COMMISSION

The eighth annual meeting of the gallery commission was held in the Regents' room of the Institution at 10.30 a. m., December 11, 1928. The members present were Messrs. James E. Fraser, J. H.

Gest, John E. Lodge, Charles Moore, James Parmelee, E. C. Tarbell, W. H. Holmes, and C. G. Abbot, secretary of the Smithsonian Institution. In the absence of the chairman of the commission, Mr. Gari Melchers, Mr. Charles Moore was elected temporary chairman.

The minutes of the previous annual meeting were read and approved, followed by the reading and approval of the secretary's report on the activities of the gallery for the year.

The committee on resolutions on the death of Dr. Charles Doolittle Walcott, Secretary of the Institution, appointed at the annual meeting of December 6, 1927, presented the following, which was adopted:

Whereas the National Gallery of Art Commission of the Smithsonian Institution, having learned of the death on February 9, 1927, of Dr. Charles D. Walcott, Secretary of the Smithsonian Institution and ex officio a member of this commission, has adopted the following resolution:

Resolved, That we here record our profound sorrow at the passing of this distinguished man of science, whose achievements as the head of the Smithsonian Institution expanded its renown and added greatly to the sum of human knowledge; but particularly are we desirous of expressing our sense of the loss of one who was also keenly alive to the importance of developing the art side of the Institution's activities, and to whose foresight is due the establishment of this commission as a means of insuring a high standard of excellence for the art works acquired by the National Gallery of Art.

Resolved, That these resolutions be incorporated in the present annual report of the commission to the Board of Regents and that a copy of them be transmitted by the Secretary of the commission to the family of Doctor Walcott.

DR. C. G. ABBOT,
DR. W. H. HOLMES,
Committee.

The chairman asked Mr. Lodge in regard to the relationship of the Freer Gallery to the National Gallery, and Mr. Lodge explained that, as he understood it, Mr. Freer had desired that his gift should be regarded as a branch of the National Gallery, to be separately provided for and installed.

The chairman called attention to a project advocated by persons interested in the promotion of American art, which project favors the establishment of a fund to be devoted to the aid of young, promising artists. The suggestion was favorably commented upon and the feasibility of securing support of the undertaking was discussed at some length. The chairman was authorized to take the matter up with such persons and institutions as he might find sympathetic.

THE HENRY WARD RANGER FUND

The paintings purchased during the year by the council of the National Academy of Design as provided by the Henry Ward Ranger

bequest are as follows, including the names of the institutions to which they have been assigned:

Title	Artist	Date of purchase	Assignment
69. South Dakota Evening	Jes W. Schlaikjer	December, 1928	Vassar College, Poughkeepsie, N. Y.
70. Fifth Lake	Edgar Payne	do	The James Lee Memorial Academy of Arts, Memphis, Tenn.
71. The Harvest Moon	Charles Melville Dewey	January, 1929	Not reported.
72. The Golden Hour	George Elmer Browne	March, 1929	Michigan State College of Agriculture and Applied Sciences, East Lansing, Mich.
73. The Burro	Ernest L. Blumenschein, N. A.	do	The Brooklyn Institute of Arts and Sciences, Brooklyn, N. Y.
74. Hemlock Grove	Emil Carlsen, N. A	do	The Portland Society of Art, Portland, Me.
75. Summer Plumes	Gustave Cimiotti	do	The Newark Museum Association, Newark, N. J.
76. Fishing Fleet	Malcolm Humphreys	do	Not reported.

The paintings purchased from the Ranger fund during the last fiscal year and unassigned at its close (1927–28) have subsequently been assigned as follows:

63. Cypripedia, by Sergeant Kendall, N. A.; to the California Palace of the Legion of Honor, San Francisco, Calif.

The project of assembling the Ranger purchases thus far made for temporary exhibition in the National Gallery of Art has been considered from time to time, but action has been delayed, due to the lack of funds requisite for expenses of packing and shipping. At the special meeting of the commission, held April 13, 1929, Mr. Gari Melchers, chairman, made the welcome announcement that the Carnegie Corporation of New York had generously allowed $1,000 for this purpose. It was deemed advisable by members of the commission present to hold the exhibition not later than December 1, 1929, and Secretary Abbot volunteered to take up at once the necessary correspondence with the National Academy of Design and with the several institutions holding the works.

SPECIAL EXHIBITIONS HELD IN THE GALLERY

Six loan exhibits of art works added greatly to the interest of the year's activities; these, briefly summarized, are as follows:

PORTRAITS BY M. L. THEO DUBÉ

Four portraits by the distinguished French painter, M. L. Theo Dubé, membre Societaire de la Société des Artistes Français, were

exhibited in the middle room of the gallery from November 16 to December 14, 1928. The group included two compositions—A Tramp and Coquetry, and portraits of President Woodrow Wilson, 1913, and Senator Mascurand, of France.

GOTHIC CATHEDRALS OF FRANCE

A noteworthy collection of paintings of the Gothic cathedrals of France, 27 in number, by Pieter van Veen, Dutch-American painter, was exhibited under the patronage of his excellency the French ambassador in Washington, the Hon. Paul Claudel, from December 8 to 31. A printed illustrated catalogue of the collection was supplied by the artist and cards of invitation were issued for a special view on December 8.

MINIATURES BY EDWARD GREENE MALBONE

A very important exhibit of early American miniatures, the life work of Edward Greene Malbone (1770–1807), was shown in the middle room of the gallery from February 23 to April 21, 1929. Cards of invitation to the opening were issued. The collection was assembled as the result of extensive correspondence and appeal and arranged for exhibition by Mr. Ruel P. Tolman, curator of graphic arts in the National Museum. Mr. Tolman prepared also the illustrated catalogue supplied by the gallery.

WATER-COLOR PAINTINGS OF INDIA

A collection of 42 masterly water-color paintings by William Spencer Bagdatopoulos, English painter and etcher, of scenes and figure subjects in India, was shown in the northeast room of the gallery February 15 to March 15, 1929. A catalogue of the collection was furnished by the artist.

ARCTIC AND ANTARCTIC SCENES AND CHARACTER STUDIES

On March 2 the gallery received and placed on view in the south room an important collection of paintings by Frank Wilbert Stokes. Mr. Stokes is probably the only person who has visited and painted in both polar regions. His collection is the fruit of four separate expeditions and numbers 500 works covering a wide range of subject matter. The selections forwarded and placed on view in the gallery comprise 17 landscapes, 10 portrait studies of Eskimo, and 10 minor landscape studies. Mr. Stokes's work has the full approval of Commander R. E. Byrd, United States Navy, with whom he visited the scenes and people portrayed. The collection remains on view at the close of the year.

PAINTING AND SCULPTURE BY AMERICAN NEGRO ARTISTS

An exhibition of 64 paintings and several pieces of sculpture, the work of American negro artists, was shown in the foyer of the museum from May 16 to 27, 1929. This collection was shown in New York City in connection with the annual William E. Harmon awards for distinguished achievement among negroes. It was brought to Washington under the patronage of the committee on race relations of the Washington Federation of Churches and under the immediate supervision of Dr. Anson Phelps Stokes, canon of Washington Cathedral, chairman of the committee, and Dr. Emmett J. Scott, secretary-treasurer of Howard University, secretary. Invitation cards were issued by the gallery and a catalogue of the collection was supplied by the committee.

REINSTALLATION OF COLLECTIONS

The two-feathered Serpent Column models, the mutilated originals of which are still in place in the portal of the Pyramid Temple known as the "Castillo," or castle, in Chichen Itza, Yucatan, were removed from the lobby to the second floor, thus taking their place with the archeological collections to which they pertain. The space at the east end of the lobby thus made vacant is now occupied by the handsome mantelpiece and fireplace, by Richardson, transferred to the Museum when the residence of Benjamin H. Warder was dismantled in 1924.

THE ALFRED DUANE PELL COLLECTION

In April, 1929, a large portion of the Alfred Duane Pell collection which, due to lack of space in the National Gallery, had been installed temporarily in the Arts and Industries Building, was transferred to the Pell alcove at the north end of the gallery. A series of busts of Sèvres biscuit ware belonging to the collection, remains for the present in the Arts and Industries Building. A catalogue of this material, 996 numbers, was compiled by Miss Helen A. Olmsted, of the department of arts and industries, National Museum, under the expert supervision of Dr. S. W. Woodhouse.

ART WORKS RECEIVED DURING THE YEAR

Accessions of art works by the Smithsonian Institution, subject to transfer to the National Gallery on approval of the advisory committee of the National Gallery of Art Commission, are as follows:

Portrait bust in bronze of the Hon. Elihu Root, by James Earle Fraser, N. A. A replica of the bust made for the Carnegie Corporation of New York. (Donor not ascertained.)

Four specimens of modern Japanese cloisonné; gift of Seth B. Robinson, jr., and T. Dudley Robinson, of New York City.

The John Gellatly collection of art objects, presented to the Nation for eventual assignment to the National Gallery of Art. Accepted by Congress under a joint resolution approved by the President on June 6, 1929. This collection is now housed in the Heckscher Building, 730 Fifth Avenue, New York City, where it is to remain for four years, becoming then available for transfer to the gallery.

LOANS ACCEPTED BY THE GALLERY

A painting entitled "Mist in Kanab Canyon, Utah," by Thomas Moran, 1892; lent by Mrs. Bessie B. Croffut, Washington, D. C.

A painting entitled "A Rainy Day," by Peter Moran; lent by the Misses Grandin, Washington, D. C.

Two paintings by Gilbert Stuart—portrait of Thomas Amory, of Boston, and portrait of George A. Otis; lent by Mrs. O. H. Ernst and Miss Helen Amory Ernst, of Washington, D. C.

Portrait bust in marble of Mrs. Nicholas Longworth, by Moses W. Dykaar; lent by the sculptor.

Portrait bust in bronze of Hon. Wade H. Ellis, by Joseph Anthony Atchison; lent by the sculptor.

Three paintings by old masters—Madonna and Child, by Alonzo Cano (1601–1667); The Madonna, by Carlo Dulci (1616–1686); and Saint with Book, by Giuseppe Ribera (Spagnoletto) (1588–1656); lent by Mr. and Mrs. Maxim Karolik, Washington, D. C.

Portrait of Mrs. Charles Eames, by Gambardella; lent by Mrs. Alistair Gordon Cumming, Washington, D. C.

DISTRIBUTIONS

Two landscape models by G. C. Curtis, sculptor, 1902, showing the park scheme of the city of Washington, lent to the gallery in 1917 by the National Commission of Fine Arts, were withdrawn by the commission through Mr. H. P. Caemmerer, secretary and executive officer.

The collection of paintings, landscapes, colonial mansions, etc., by John Ross Key, originally received January 15, 1927, as a temporary exhibit by the artist's widow, and retained at her request and the request of certain Members of Congress, in order that it might be available for inspection by a suggested congressional committee, was withdrawn by Mrs. John Ross Key April 25, 1929.

The painting Love and Life, by George Frederick Watts, a gift of the artist to the American people in 1893 and shown at the World's Columbian Exposition at Chicago, accepted by act of Congress July 23, 1894, and transferred from the White House to the National

Gallery March 21, 1921, was recalled to the White House by President Herbert Hoover on March 11, 1929, where it has an honored place in his study.

An early painting by George Inness, lent to the gallery by Col. Henry C. Davis, United States Marine Corps, was withdrawn by Mrs. Davis, his widow, of Coronado, Calif.

An Italian masterpiece, The Immaculate Conception with the Mirror, by Murillo, lent to the gallery by Mr. DeWitt V. Hutchins on April 28, 1928, was withdrawn by Mr. Hutchins and shipped by his order to Thomas J. Kerr, New York City, on June 24, 1929.

The portrait bust in plaster of President James Monroe, by Mrs. Margaret French Cresson, was withdrawn by the sculptor.

The portrait of Surg. Bailey Washington, jr., United States Navy, (1787–1854), by an artist unknown, was withdrawn by Mr. John Washington Davidge upon order from the owner, Miss Alice M. Reading, of Reading, Calif.

LOANS BY THE GALLERY

At the request of Mrs. Herbert Hoover, two paintings belonging to the William T. Evans collection of contemporary American paintings—The Flume, Opalescent River, Adirondacks, by Alexander Wyant, and Castle Creek Canyon, South Dakota, by Frank De Haven—were lent to the White House, for temporary embellishment of the state dining room, on May 23, 1929.

MISCELLANEOUS

Four large ebonized kensington cases of the gem type have been added to the gallery furnishings; these are for the accommodation of that portion of the Alfred Duane Pell collection recently transferred from the Arts and Industries Building. Four No. 500 "window spot reflectors" have been installed in the skylight over the middle room of the gallery for the better lighting of the art works on dark days.

LIBRARY

The gallery library has been increased by gift, purchase, and subscription in volumes, pamphlets, periodicals, etc.

A gift made possible through a fund in Yale University established by Canon Anson Phelps Stokes, consisting of a set of 14 etchings made for the Yale University Press by Louis Orr, entitled "Ports of America," was added to the library pending other assignment when the various departments of the gallery are more fully established.

PUBLICATIONS

Holmes, W. H. Report on the National Gallery of Art for the year ending June 30, 1928. Appendix 2, report of the secretary of the Smithsonian Institution for the year ending June 30, 1928, pp. 52–62.

Catalogue of A Group of Original Paintings of the Gothic Cathedrals of France, by Pieter van Veen, on view in the National Gallery, Natural History Building, United States National Museum, December 8 to December 31, 1928. Under the patronage of his excellency the French ambassador, Hon. Paul Claudel. Washington, 1928; 6 pp.; 2 plates.

Catalogue of A Collection of Water-Color Paintings of India, by W. S. Bagdatopoulos, on view in the National Gallery of Art, United States National Museum Building, February 15 to March 15, 1929. Washington, 1929, 4 pp.

Catalogue of Miniatures and Other Works, by Edward Greene Malbone, 1777–1807. February 23–April 21, 1929. Washington, 1929, 21 pp.; 5 plates.

Catalogue of An Exhibition of Paintings and Sculpture by American Negro Artists, at the National Gallery of Art, Smithsonian Institution, Washington, D. C. May 16–May 29, 1929. Washington, 1929; 15 pp.; 11 illustrations.

Respectfully submitted.

W. H. Holmes, *Director*.

Dr. C. G. Abbot,
Secretary, Smithsonian Institution.

APPENDIX 3

REPORT ON THE FREER GALLERY OF ART

SIR: I have the honor to submit the ninth annual report on the Freer Gallery of Art for the year ending June 30, 1929:

THE COLLECTIONS

Additions to the collections by purchase are as follows:

BOOKBINDING

29.20. Persian, sixteenth-seventeenth century. Turkish school. Red leather, with decorations in stamped arabesques on gold.

29.21. Egyptian, fifteenth century. Brown leather, decorated in blind and gold tooling.

29.22. Egyptian, fourteenth century. Dark-brown leather, decorated in blind and gold tooling.

29.23. Egyptian, fifteenth century. Red leather, decorated in blind and gold tooling.

29.24. Persian, sixteenth century. Light-brown leather, lined with rose-red leather. Decorations in blind and gold tooling, and in stamped arabesques on gold and blue grounds.

BRONZE

29.4. Chinese, sixth century or earlier. Period of the Six Dynasties. A large mirror, the back decorated with engraved silhouettes of gold and silver set in lacquer.

29.17. Chinese, seventh-tenth century. T'ang period. A mirror with phoenix and running animal figures in relief on the back.

29.18. Chinese, sixth-seventh century. Sui period. A mirror with formalized design of palmettes in circles in relief on the back.

29.19. Chinese, third century B. C.(?). Han period or earlier. A sword, with ornamental designs inlaid in gold on the pommel, and in gold and turquoise on the guard, while both sides of the blade carry inscriptions, also inlaid in gold.

GLASS

29.8. Syrian, thirteenth-fourteenth century. A pilgrim bottle, of transparent blown glass, decorated with polychrome enamels and gold.

MANUSCRIPTS

29.63. Persian, seventeenth century. By Kemāl ad-Din. A page of calligraphy in four colors on a pinkish-cream paper. Ornaments of floral arabesques on a gold ground. Signed.

29.64. Persian, seventeenth century. By Kemāl ad-Din. A page of calligraphy in three colors on a pinkish-cream paper. Ornaments of floral arabesques on grounds of gold and blue.

29.65. Persian, seventeenth century. A page of calligraphy in three colors on blue paper with a floral ornament in gold.

29.66. Turkish, sixteenth century. A page of *nastaliq* script in white on a green ground. The writing is cut from paper and mounted. Ornamental band in colors and gold.

29.67. Turkish, sixteenth century. A page of *nastaliq* script in white on a blue ground. The writing is cut from paper and mounted. Ornamental band in colors and gold.

29.68. North African, sixteenth century. Two sheets of parchment (from a
29.69. book) with *Maghrībi* writing on both sides in brown and blue. Ornaments in gold and color.

29.70. Persian, eleventh-twelfth century. A sheet of paper (from a book) with *Kufic* script on both sides in black, red, and gold. Page ornaments in gold and black.

29.71. Egyptian(?), eighth-ninth century(?). A sheet of parchment (from a book) with *Kufic* script on both sides in black and red. Ornaments in gold, black, and red.

29.72. Egyptian(?), eighth-ninth century(?). A sheet of parchment (from a book) with *Kufic* script on both sides in black and red.

29.73. Egyptian, thirteenth century. A frontispiece of a Koran with *naskh* script in black on paper. Borders, medallions, and small ornaments in gold and black.

29.74. Egyptian, thirteenth century. A frontispiece of a Koran with *naskh* script in black on paper. Borders, medallions, and small ornaments in gold and black.

PAINTING

29.1. Chinese, dated in correspondence with A. D. 797. A fragment of a Buddist scripture from Tun-huang, with figures of Buddhas and Bodhisattvas. In colors on paper.

29.2. Japanese, eleventh century. Fujiwara Buddhist. *Hōrōkaku Mandara:* The Buddha and attendant divinities. In color and gold on silk; mounted as a panel.

29.3. Indian, seventeenth century. Mughal. A prince and an ascetic. In colors and gold on paper.

29.76. Indian, seventeenth century. A pilgrim and an ascetic in conversation. In delicate color on paper.

29.25. Persian, thirteenth century. Mongol school. Twenty-two illustrations
29.46. on loose leaves of a *Shāh Nāmah*, rendered in colors, black, gold, and silver (oxydized).

29.75. Persian, sixteenth-seventeenth century. Turkish school. A court scene in bright colors and gold on paper.

29.77. Persian, about 1600. Shāh 'Abbās school, in the style of Yūsuf. A man playing on a lute. In full color and gold on paper.

29.78. Persian, seventeenth century. Two pheasants. In full color and gold on paper.

29.79. Persian, middle fifteenth century. Timurid school. A warrior of Tīmūr. Drawn in black and slight tint, with ornamental details in gold.

29.80. Indian, early seventeenth century. Mughal, time of Jahāngīr. A love scene. In colors and gold on paper.

29.81. Indian, middle seventeenth century. Mughal, time of Shāh Jahān. Portrait of Asālat Khān. In white, black, color, and gold on paper.

POTTERY

29.6. Chinese, T'ang dynasty. A cylindrical jar with ribbed sides and three stump feet, glazed in blue outside and in yellow inside.

29.7. Chinese, Sung dynasty. Chün ware. A flowerpot with 12 lobed sides and festooned rim; glazed in deep strawberry-red and blue.

29.12. Chinese, Sung dynasty. Chien ware (Honan type). A covered jar, glazed in black with a painted ornament in metallic brown.

29.13. Chinese, Sung dynasty. Tz'ŭ chou ware. A vase with trumpet-formed mouth, with a floral ornament in black on a white ground.

29.14. Chinese, Sung dynasty. Ying ching ware. A covered box, glazed in pale greenish-blue, with a stamped phoenix design on the cover in slight relief.

29.15. Chinese, T'ang dynasty. A figure of a dog, biting at one leg, seated on a hollow base; glazed in white with a mingled overflow of blue and yellow.

29.9. Persian, eleventh–thirteenth century. Rhages. A jug with a bottle neck, painted with figure designs, over glaze, in blue, green, black, and yellow.

29.10. Persian, eleventh–thirteenth century. Rhages. A jug with a wide cylindrical neck, glazed in white, and decorated in applied relief outlined with red, with other adornments of red, green, and blue enamels and gold.

29.11. West Asian. Rakka. A plate, glazed in white, with a sphinx figure in slight relief, enameled in green, dark blue, and brown.

SILVER

29.5. Chinese, ninth century. T'ang dynasty. A covered box, with a delicate floral design engraved upon it.

29.16. Chinese, ninth century. T'ang dynasty. A cup with a delicate floral design engraved upon the outside.

Curatorial work within the collection included documentary study of Chinese and Japanese inscriptions on several new purchases and on various objects already included in the collection. Many objects have been submitted for an expert opinion upon them or for translation of their Chinese, Japanese, or Tibetan inscriptions. The total number of such reports covers 681 objects and 56 photographs and tracings. The collection known as "A gold treasure of the late Roman period," a group of Byzantine objects of the fourth to sixth century, has been catalogued, and the collection of antique glass, which was listed in the Freer inventory, S. I. 189, as "Egyptian glass," has been classified for the first time and duly catalogued. This collection contains 1,271 manufactured objects, ranging from vases of several inches in height to minute beads and embracing

many types of early glass from Egypt, Syria, and elsewhere. In addition to these there are 80 small rods used in the making of mosaics, and 44 shells, probably from ancient graves and used as amulets, making a total of 1,395 objects. In this work the curator had the assistance of Dr. Gustavus A. Eisen, author of Glass, New York, 1927.

Repairs tending to the preservation of objects in the collection have been completed as follows:

(1) Resurfacing:
- 2 oil paintings by Whistler.

(2) Remounting:
- 1 Japanese screen.
- 1 Japanese panel.
- 2 Chinese *makimono.*
- 1 Chinese panel.

(3) Mending of breaks:
- 17 pieces of Chinese bronze.
- 7 pieces of Chinese jade.
- 5 pieces of Chinese pottery.
- 8 pieces of Egyptian glass.
- 1 piece of Egyptian bronze.
- 1 piece of Korean pottery.
- 1 piece of Japanese pottery.
- 2 pieces of Chinese stone sculpture.

These pieces were broken when purchased and have been put in condition for the first time.

Changes in exhibition during the year have involved 106 different objects, itemized as follows:

- 25 Chinese bronzes.
- 6 Chinese paintings.
- 2 Chinese stone sculptures.
- 28 Chinese pottery.
- 6 Japanese screens.
- 5 Japanese paintings.
- 15 Near Eastern pottery.
- 19 Near Eastern paintings.

THE LIBRARY

During the year there have been added to the main library 231 volumes and to the library of the field staff 114, making a total of 345 volumes; 41 unbound periodicals and 129 pamphlets to the main library and 53 periodicals and 62 pamphlets to the field library, making totals of 94 periodicals and 191 pamphlets. Thirty-four volumes of *Kokka* were rebound and 9 other volumes. The field library sent 39 volumes to the bindery. A list of new accessions to the library, in its two divisions, accompanies this report as Appendix A, Parts I and II (not printed).

REPRODUCTIONS AND PAMPHLETS

Two hundred and eighty-one new negatives of objects have been made. Of these, 139 were made for registration photographs and 142 in response to special orders. The total number of reproductions available, either as carbon photographs or as negatives from which prints can be made upon request, is now 2,689.

Three hundred and forty-two lantern slides have also been added to the collection, making a total of 829 available for study and for sale.

The total numbers of sales of reproductions, at cost price, are as follows: Photographs, 2,156; post cards, 18,334; lantern slides, 60; negatives, 5. Two hundred and eighty-five lantern slides have been loaned for lecture purposes.

Of booklets issued by the gallery, the following number were sold at cost price:

F. G. A. pamphlets	143
Synopsis of History folders	154
List of American paintings	69
Annotated Outlines of Study	21
Gallery books	277
Floor plans	17

BUILDING

The shop has been occupied constantly with the usual repair work, the making of stands, frames, and easels for exhibition galleries, and of furniture and equipment for the building. A detailed report of shopwork, including painting, accompanies this report as Appendix C (not printed).

ATTENDANCE

The gallery has been open every day, with the exception of Mondays, Christmas Day, and New Year's Day, from 9 until 4.30 o'clock. The total attendance for the year was 116,303. The aggregate Sunday attendance was 41,411, with an average Sunday attendance of 796. The week-day attendance amounted to 74,892, with an average of 290. Of the 2,101 visitors who came to the offices, 207 came for general information, 20 to study the building and museum methods, 54 to submit objects for examination, 327 to see objects in storage, 166 to study in the library, 75 to see the facsimiles of the Washington Manuscripts, 7 to make photographs and sketches in the exhibition galleries, 17 to make tracings from illustrated books in the library, and 228 to purchase photographs. Ten classes, in groups ranging in number from 3 to 15, were given instruction in the study rooms, and 12 groups ranging from 1 to 40 persons were given docent

service in the galleries. On November 19, 1928, Mr. Bishop lectured in the auditorium on The Development of Chinese Arts, with lantern-slide illustrations, before an audience composed of the art section of the Twentieth Century Club and the department of fine arts of the District Federation of Women's Clubs.

FIELD WORK

The work of the field staff has been carried on during the past year without interruption, in this country as well as in China, and gratifying progress has been made in both.

The labor involved has now reached very considerable portions and is steadily growing in amount. In addition to that of a routine nature, it has come to include the handling of a large correspondence with individuals and organizations in this country and abroad, the writing of articles and the delivering of lectures designed to promote an intelligent interest in the civilizations of the Far East, and the maintenance of a cordial understanding with the Chinese Government. Negotiations with the latter's National Research Institute have been brought to a highly satisfactory conclusion and have already borne abundant fruit. The plan inaugurated by the American Council of Learned Societies for the undertaking of a world-wide survey of the resources at present available for the prosecution of Far Eastern research has also received active assistance from our field staff and is to be put in execution in the near future.

Every effort has likewise been made to bring our field library of reference, with its books, periodicals, pamphlets, clippings, photographs, maps, etc., to a high state of efficiency and usefulness. The labor devoted to this task has already amply justified itself.

Dr. C. Li, of our field staff, who was in this country last summer, returned to China in the autumn by way of Europe, Egypt, and India. As a direct result of our understanding with the Chinese Government the latter extended to him on his arrival every assistance in the planning and prosecution of important archeological excavations in the Province of Honan, one of the principal centers of the archaic Chinese civilization of the protohistoric period. A full report of his finds during the past spring is awaited with interest and should throw much new light on a hitherto dark page of culture history.

It is highly gratifying to note that political conditions in China have undergone a steady improvement during the past year. All present indications appear to unite in justifying the confident expectation that our work in the field will be carried on without interference or interruption of any kind.

During the winter season Mr. Bishop gave the following lectures, in addition to that mentioned above:

Archeological Research in China, before the Cosmos Club, Washington, October 22.

Exploring and Excavating in China, at the Museum of the University of Pennsylvania, January 19.

The Bronze Age in China, at the Metropolitan Museum of Art, New York, on February 9.

Travels in China, at the Chevy Chase School, Chevy Chase, Md., March 3.

An account of the activities of our field staff, briefly outlined above, is given in detail in Appendix B, submitted herewith (not printed).

PERSONNEL

Mr. Archibald G. Wenley, field assistant, arrived from Paris, France, on September 21, and spent a few days at the gallery before going to Japan. The past eight months he has been stationed at Kyōto.

Dr. Chi Li arrived in Peking on November 21 and has since been engaged in archeological research.

Mr. Y. Kinoshita, of the Boston Museum of Fine Arts, worked at the gallery from January 14 to June 27 on the preservation of oriental paintings.

Mr. S. Mikami, of New York, worked at the gallery in three periods between March 25 and June 27 on repairs to various objects of jade, bronze, stone, glass, and pottery.

Dr. G. A. Eisen, of New York, spent two weeks in April at the gallery, classifying the collection of ancient glass.

Respectfully submitted.

J. E. Lodge,
Curator, Freer Gallery of Art.

Dr. C. G. Abbot,
Secretary of the Smithsonian Institution.

APPENDIX 4

REPORT ON THE BUREAU OF AMERICAN ETHNOLOGY

SIR: I have the honor to submit the following report on the field researches, office work, and other operations of the Bureau of American Ethnology during the fiscal year ended June 30, 1929, conducted in accordance with the act of Congress approved May 16, 1928. The act referred to contains the following item:

American ethnology: For continuing ethnological researches among the American Indians and the natives of Hawaii, the excavation and preservation of archeologic remains under the direction of the Smithsonian Institution, including necessary employees, the preparation of manuscript, drawings, and illustrations, the purchase of books and periodicals, and traveling expenses, $60,300

Mr. M. W. Stirling entered upon his duties as chief of the bureau August 1, 1928, succeeding Dr. J. Walter Fewkes, who retired January 15, 1928.

During the months of September and October Mr. Stirling worked with a group of Acoma Indians who were visiting Washington and secured from them in as complete form as possible the origin and migration myth of that very conservative tribe. This myth not only describes the emergence of the first human beings from the underworld but also explains the origin and functions of the pantheon of demigods and heroes connected with the legend. The myth likewise explains the origin and function of the clans and the medicine societies and the reason for the many ceremonies practiced. In connection with this work phonographic records were made of 66 songs, many of which have been transcribed by Miss Frances Densmore, as described in her report. This information fills an important gap in our knowledge of the oldest inhabited pueblo in the United States.

Mr. Stirling spent the months of March and April in Florida, where a survey was made of the mounds in the vicinity of Tampa Bay. An interesting discovery was made of a series of mounds composed of mixed sand and shell, constructed at a distance of about 4 miles inland, parallel to the shore, and in each instance directly back of a large shell mound located on the salt water. Preliminary excavations were made at Cockroach Point, Palma Sola, and Safety Harbor. The shell mound at Cockroach Point is the largest on the west coast of Florida and is composed entirely of shell and bone, refuse from the meals of the Indians who formerly occupied the

site. Collections of shells and bones were made in the different levels of the mound, together with human artifacts associated with them, with a view to establishing a culture sequence.

The site at Safety Harbor was determined to be of the same culture as that excavated at Weeden Island during the winters of 1923 and 1924.

The large sand mound at Palma Sola proved to be of exceptional interest and was selected as a site for intensive excavation next winter.

During the latter part of April Mr. Stirling visited Chicago for the purpose of delivering lectures before the Geographic Society of Chicago and the anthropologists of Chicago and vicinity. From Chicago he went to Memphis, Tenn., where he attended the meeting of the Tennessee Academy of Sciences and addressed the society at their annual banquet. Proceeding from Memphis to Macon, Ga., he visited the large mounds on the site of Old Ocmulgee Town, traditional founding place of the Creek Confederacy.

During the third week in May Mr. Stirling attended the conference of Mid-Western Archeologists, which was held at St. Louis under the auspices of the National Research Council, and as representative of this body went to Montgomery, Ala., to deliver an address at the unveiling of a monument by the Alabama Anthropological Society on the site of old Tukabatchi.

He also attended the meeting of the American Association for the Advancement of Science in New York in December, 1928, as representative of the United States Government.

Dr. John R. Swanton, ethnologist, was engaged during the year in completing the proof reading of his bulletin on the Myths and Tales of the Southeast, which has been released for publication.

Considerable material was added to his manuscript paper entitled "Source Material for Choctaw Ethnology." Part of this was collected from the archives of the State Department of Archives and History at Jackson, Miss., and some from the eastern Choctaw at Philadelphia, Miss., in July, 1928. Also, a great deal more work was devoted to the projected tribal map of aboriginal North America north of Mexico and to the accompanying text, including the incorporation of some valuable notes furnished by Mr. Diamond Jenness, chief of the division of anthropology of the Geological Survey of Canada.

Work was continued throughout the year on the Timucua dictionary which, in spite of the elimination of a large number of cards on account of closer classification and the correction of errors, still fills 14 trays.

Shortly after July, 1928, Dr. Truman Michelson, ethnologist, left Washington to renew his research among the Algonquian Tribes of

Oklahoma. He first studied the linguistics, sociology, and physical anthropology of the Kickapoo. Kickapoo in certain respects is very important linguistically. While working on Arapaho he was able to formulate many phonetic shifts of complexity. Even so, the amount of vocabulary that can be proved to be Algonquian is very small. The grammatical structure is, however, fundamentally Algonquian. It is also true that there are a few traits which are distinctly un-Algonquian; for example, the order of words.

The first week in August Doctor Michelson went to Tama, Iowa, to renew his work among the Foxes. He there restored phonetically some texts previously obtained in the current syllabic script and worked out some translations. He also obtained some grammatical notes on these texts. Some new Fox syllabic texts were collected and new and important ethnological data were obtained.

Doctor Michelson returned to Washington in September. He corrected proofs of Bulletin 89, Observations on the Thunder Dance of the Bear Gens of the Fox Indians, and prepared for publication by the bureau a memoir entitled "Notes on the Great Sacred Pack of the Thunder Gens of the Fox Indians." Early in June Doctor Michelson left for Oklahoma, where he obtained more Kickapoo linguistic notes, further elucidating the relation of Kickapoo to Fox. From this it appears that Kickapoo diverges more widely in idiom than hitherto suspected. He also secured some Kickapoo texts in the current syllabic script and obtained new data on social organization. Some brief Shawnee linguistic notes were collected. These show that while Shawnee is in certain respects very important for a correct understanding of Fox phonology, as a whole it is not as archaic. It is also now clear that Shawnee is further removed from Sauk and Kickapoo than he had previously surmised. Doctor Michelson witnessed several Kickapoo dances and attended a Shawnee ball game.

In June, 1929, Mr. John P. Harrington, ethnologist, completed his report on the Taos Indians, who inhabit a large pueblo on an eastern affluent of the Rio Grande in north-central New Mexico. These are the northernmost of the New Mexico Pueblo Indians and are peculiarly interesting because of the long intimate relations they have had with the Jicarilla Apaches, Utes, Comanches, and other tribes of Great Plains culture. During the period of Spanish domination in New Mexico the Taos had to play the double and difficult rôle, because of their frontier position, of persuading the Spanish that they were really on their side, and the Plains Indians that they were really on theirs. The relations with the Plains Indians existed far back in Taos history and amounted at times to the incorporation of large bodies of these Indians in the blood which went to make up the present-day Taos. And there is a still more remote

and fundamental connection with one group of Plains Indians, namely, the Kiowa. The Taos language, which was the language of one of the ancient groups which contributed to the composition of Taos, has been determined to be a dialect of Kiowa, which seems to indicate that this contingent of the Taos population at least, like the Kiowas themselves, once lived in the northern region of the Rocky Mountains, probably in what is now Canada.

Grasping still another opportunity to check the old and new information on this region, studies on the related Karuk Indians of the central Klamath River region of California were resumed during field work on the coast and were continued throughout the year, resulting in an accumulation of carefully analyzed material, a large part of which is now ready for publication. The work consists of many divisions of information, including the grammar of the language, its sounds, its peculiar musical intonations, and the system of long and short consonants and vowels; the history of the tribe, which remained intact and unspoiled up to 1850; the census, with the peculiar old personal names; the villages, which were strung out along the river and its tributary creeks; the construction of the living houses and sweat houses, and the description of all the manufactures, and the process of making the objects, all in Indian; the social life, an organization without chiefs; the great festivals and the various dances; feuds, wars, and peace making; sucking and herb doctors, and the sources of their power; medicine formulas and myths, all in the language, for any other record of them would be inadequate. This information is accompanied by photographs and phonograph records and is rapidly approaching completion for publication as a report of the bureau.

Early in June Mr. Harrington went to Chaco Canyon, N. Mex., for the purpose of making further study of the Pueblo Indian languages, notably the relation of Zuñi and Keresan to the newly discovered Kiowan family. Cooperating with students of the University of New Mexico attending the university summer school being held at Chaco Canyon under the joint auspices of the State University and the School of American Research, a minute comparison was made of the Taos and Zuñi languages, resulting in the discovery of the genetic relationship of these two languages, a relationship which can be traced through hundreds of words of similar sound and identical construction, which was long ago hinted at by the discovery of such words as *lana*, big, and *papa*, older brother, which are the same in sound and meaning in both languages. About 200 kymograph tracings were made. Similar genetically related words and features were also discovered in the Keresan language. Cooperating in this work were Miss Sara Goddard, Miss Clara Leibold, Miss Anna

Risser, Miss Janet Tietjens, Miss Winifred Stamm, Mr. Reginald Fisher, and several other students. The results are ready for publication, including the kymographic alphabet, which is mounted and ready for the engraver.

The months of July and August, 1928, were spent by Dr. F. H. H. Roberts, jr., archeologist, in completing archeological investigations along the Piedra River in southwestern Colorado. During that time the remains of 50 houses belonging to the first period of the prehistoric Pueblo peoples were excavated and examined. As a result of those researches it was possible to determine a 3-stage chronological development of the house types in the district as well as to postulate very definite reconstructions of the dwellings. An additional discovery was that in the arrangement of the structures the builders had developed the prototype of the unit house which was the characteristic building of the following stage, the Pueblo II period. Besides the work in house remains, a number of burial mounds were explored and many skeletons and objects of the material culture of the people were obtained. The latter include a large number and variety of pottery specimens, many of which represent an entirely new feature in the ceramic industry, bone and stone implements, and ornaments. The work as a whole gives a clear-cut picture of the life and conditions prevailing at a time of instability and disturbance due to an influx of new peoples, with its attendant cultural transition.

On the completion of the work along the Piedra River one week was spent in a reconnaissance of the Governador district in northern New Mexico. The Governador region includes the Governador, Burns, La Jara, and Frances Canyons. The latter are of special archeological and ethnological interest, because it was to that section that a large group of the Pueblo Indians from the Jemez villages fled after they had been disastrously defeated in the Battle of San Diego Canyon during the month of June, 1696, by Spanish forces engaged in the reconquest of the Southwest. The ruins of the dwellings built by the refugees are in a good state of preservation and furnish excellent information on the methods and styles of house building prevalent at that time. At the close of the Governador explorations Doctor Roberts returned to Washington, reaching there the middle of September.

During the autumn illustrations were prepared to accompany a manuscript entitled "Recent Archeological Developments in the Vicinity of El Paso, Tex.," which was published in January, 1929, as volume 81, No. 7, of the Smithsonian Miscellaneous Collections. Proof of another paper entitled "Shabik'eshchee Village, A Late Basket Maker Site in the Chaco Canyon, New Mexico," was corrected,

and this appeared in June, 1929, as Bulletin 92 of the Bureau of American Ethnology.

Considerable time was spent in the laboratory of the division of American archeology of the United States National Museum in working over the collection made during the excavations along the Piedra River. A portion of this work included the restoration, from fragments found in the various houses, of a number of unusually fine culinary and storage jars and a series of decorated bowls.

From January to June a 545-page manuscript on the work in southwestern Colorado was prepared. Accompanying this report are 40 text figures drawn by Doctor Roberts. The figures include 64 drawings, consisting of maps of the San Juan archeological area and the Piedra district, outlines of the various village and house groups, restorations of the different forms of dwellings, details in building construction, outline groups of pottery forms, and designs from decorated ceramic containers.

On May 11, 1929, Doctor Roberts left Washington for Denver, Colo., where one week was spent in studying museum specimens. From Denver he proceeded to Gallup, N. Mex., where he outfitted for work in the region of the Long H Ranch, eastern Arizona, 45 miles from the Pueblo of Zuñi. After conducting a reconnaissance a site was chosen on the Long H Ranch, 1 mile northwest of the ranch buildings, and a series of excavations started. As work progressed it was found that the site was one which had been occupied by Basket Maker III and Pueblo I peoples and that it showed the transition from the one period to the other. At the end of June, eight fine examples of pit houses had been uncovered. Excellent data on the type and character of this form of structure were obtained and several new features in the method of house grouping were observed. The burial mounds of three house clusters were examined and 30 interments exhumed. The latter were accompanied by mortuary offerings of pottery; bone and shell implements; shell beads, bracelets, and pendants; and turquoise ornaments. With the various objects found in the houses the total number of specimens reaches 300. The work has furnished valuable information on a little-known phase of the prehistoric sedentary cultures of the Southwest.

During the year Mr. J. N. B. Hewitt, ethnologist, continued his studies on the Iroquois. In 1900 and immediately subsequent years Mr. Hewitt undertook seriously to record in native texts the extant rituals, ordinances, and laws pertaining to the institutions and structure of the League or Confederation of the Five (later Six) Tribes or Nations of the Iroquois of New York State. At that time there were still living two or three men among the Iroquois of Canada who grasped more or less fully the intent and purpose of the various

institutions of this league, and Mr. Hewitt had then acquired a conversational knowledge of the two languages in which these rituals, ordinances, and laws were chiefly expressed, to wit, the Mohawk and the Onondaga. The use of the Cayuga, Oneida, and Seneca was exceptional.

From these men Mr. Hewitt obtained standard texts in the native tongues of the informants. The death of two of these informants made a study of the material furnished by them difficult. Resort was had then to other less noted informants in these matters, and there was obtained a large number of versions of portions of the standard texts already mentioned, which disclosed views and statements which it seemed impossible to harmonize with those appearing in the standard texts. It was imperative that the value of these discordant statements should be ascertained where possible and that palpable omissions from the standard texts should be utilized. The task was to ascertain in these analytical studies what was transmitted tradition and what was the personal opinion of the informant, unwittingly expressed.

This work of comparison was undertaken to secure the best possible translations, interlinear and free, of the several native texts thus studied. The texts of the Installation Chant, the Eulogy of the Founders, of the Traditional Biography of Deganawida which describes in great detail the years of difficult work which had to be done to establish the League of the Five Tribes of the Iroquois in the Stone Age of America, and also the native text of the Requickening Address of Installation, were subjected to this kind of study.

Mr. Hewitt represented the Smithsonian Institution on the United States Geographic Board. In addition to attending the meetings, he spent about three days in researches for the executive committee.

As custodian of manuscripts of the bureau, Mr. Hewitt did some classificatory linguistic work on new items acquired.

Mr. Hewitt left Washington on May 6, 1929, to continue his studies among the Iroquoian Tribes dwelling in Canada and in the State of New York. His work consisted chiefly in literal and free translation of formal native diction embodying legislative, ritualistic, and forensic thought; and also in the coordination of divergent traditional statements of traditionally historical events, in eliminating the incongruous, and in conserving the congruous. He secured 15 parcels of wampum strings, severally bearing the name of one of the burdens of the ritual, the Requickening Address of Installation.

Dr. Francis Le Flesche, ethnologist, during the last fiscal year completed Wa-sha′-be A-thi^{n}, an Osage war ceremony, composed of 270 pages of manuscript, with diagrams and illustrations; also the Wa′-wa-tho^{n}, a ceremony pertaining to the peace pipes, composed

of 129 pages of manuscript, with illustrations. In this paper is a full and detailed description of the discoidal pipes, ancient and modern, found in the Eastern States, many of which may be found in the various museums.

With the assistance of Mrs. Grace D. Woodburn, he has revised the work on the Osage Dictionary. There are approximately 19,000 words of the Osage language in common use among the tribe with English equivalent; about 17,000 English words with Osage transcriptions are given. The words, with their meanings, can not be given positively, but a clear idea of usage has been made. About 35 illustrations have been completed for this work.

SPECIAL RESEARCHES

The study of Indian music has been continued during the past year by Miss Frances Densmore, a collaborator of the bureau. Material has been submitted on the songs of the Menominee, Winnebago, Pawnee, Yuma, Acoma, and the Indians living on the Fraser, Thompson, and Squamish Rivers in British Columbia; also on a small group of songs recorded at Anvik, Alaska, and obtained through the courtesy of Rev. John W. Chapman. A comparison of the songs in this wide territory has been important in the development of the research.

Eight manuscripts have been submitted with the following titles: "Menominee Songs of Pleasure, Dances, and Manabus Legends"; "Songs of Indians Living on the Fraser, Thompson, and Squamish Rivers in British Columbia"; "Origin Song of the Dice Game and Other Winnebago Songs"; "Winnebago Songs Connected with the Recent War"; and 17 analytical tables comparing Pawnee with songs previously analyzed; "Winnebago Songs Connected with Legends, Games, and Dances"; "Acoma Songs of the Flower Dance and Corn Dance"; "Acoma Songs Used in Treating the Sick and Other Acoma Songs"; and "A Comparison Between Yuma, Acoma, and Alaskan Indian Songs," with 18 tables of analysis of Yuma songs. The number of songs transcribed and analyzed is 117, and a large number of dictaphone song records were studied without transcription. Miss Densmore corrected the proof of her book on Papago Music and the galleys of Pawnee Music; the final work of preparing the Pawnee material for publication was also done during this year. A large amount of work was done upon the preparation of Menominee and Yuma material for publications. Catalogue numbers have been assigned to all transcribed songs, except the Acoma, the highest catalogue number in her series being 1848.

During August and September, 1928, a field trip was made to the Winnebago and Menominee Tribes in Wisconsin. A large dance, continuing three days, was held by the Winnebago near Black River

Falls. This dance was witnessed, as well as numerous incidents of life in the camp, and about 50 photographs were taken.

At the conclusion of this gathering Miss Densmore went to Keshena, Wis., for further work among the Menominee. The manuscript already prepared was read to reliable members of the tribe and details were added. An interesting opportunity for seeing Menominee dances was afforded by the annual Indian fair which continued four days. Among the old dances presented were those in imitation of the fish, frog, crawfish, rabbit, partridge, and owl. The songs of these dances, together with their action and origin, were recorded. The Manabus legend concerning the first death was obtained, together with its songs, and the work included the recording of other old material.

A drum-presentation ceremonial dance, commonly called a dream dance, was held at the native village of Zoar on September 2 to 5. This was attended each day and closely observed, Miss Densmore remaining 10 hours beside the dance circle on the third day of the ceremony. Many photographs were taken.

On September 14 Miss Densmore proceeded to Tomah, Wis., and resumed her study of Winnebago music. Additional songs of the war-bundle feast, also called the winter feast, were recorded, together with several old legends and their songs, and the origin of the bowl-and-dice game, with its song. The legend of this game origin had previously been obtained among the Menominee. Numerous photographs were taken, and two drumming sticks were obtained, one being decorated with otter fur and used a generation ago by the leader at the drum.

During October, 1928, Miss Densmore went to Washington, D. C., and recorded 27 Acoma songs from Philip Sanche, who, with several Acoma Indians, was engaged in work for the chief of the Bureau of American Ethnology. A larger number of Acoma songs had previously been recorded for the chief of the bureau and these records were studied, 16 being transcribed as representative examples.

EDITORIAL WORK AND PUBLICATIONS

The editing of the publications of the bureau was continued through the year by Mr. Stanley Searles, editor, assisted by Mrs. Frances S. Nichols, editorial assistant. The status of the publications is presented in the following summary:

PUBLICATIONS ISSUED

Forty-first Annual Report. Accompanying papers: Coiled Basketry in British Columbia and Surrounding Region (Boas, assisted by Haeberlin, Teit, and Roberts); Two Prehistoric Villages in Middle Tennessee (Myer). 626 pp 137 pls. 200 figs. 1 pocket map.

Forty-third Annual Report. Accompanying papers: The Osage Tribe: Two Versions of the Child-naming Rite (La Flesche); Wawenock Myth Texts from Maine (Speck); Native Tribes and Dialects of Connecticut, a Mohegan-Pequot Diary (Speck); Picurís Children's Stories (Harrington and Roberts); Iroquoian Cosmology—Second Part (Hewitt). 828 pp. 44 pls. 9 figs.

Forty-fourth Annual Report. Accompanying papers: Exploration of the Burton Mound at Santa Barbara, Calif. (Harrington); Social and Religious Beliefs and Usages of the Chickasaw Indians (Swanton); Uses of Plants by the Chippewa Indians (Densmore); Archeological Investigations—II (Fowke). 555 pp. 98 pls. 16 figs.

Bulletin 84. Vocabulary of the Kiowa Language (Harrington). 255 pp. 1 fig.

Bulletin 86. Chippewa Customs (Densmore). 204 pp. 90 pls. 27 figs.

Bulletin 87. Notes on the Buffalo-head Dance of the Thunder Gens of the Fox Indians (Michelson). 94 pp. 1 fig.

Bulletin 89. Observations on the Thunder Dance of the Bear Gens of the Fox Indians (Michelson). 73 pp. 1 fig.

Bulletin 92. Shabik' eshchee Village: A Late Basket Maker Site in the Chaco Canyon, New Mexico (Roberts). 164 pp. 31 pls. 32 figs.

PUBLICATIONS IN PRESS

Forty-fifth Annual Report. Accompanying papers: The Salishan Tribes of the Western Plateaus (Teit, edited by Boas); Tattooing and Face and Body Painting of the Thompson Indians, British Columbia (Teit, edited by Boas); The Ethnobotany of the Thompson Indians of British Columbia (Teit, edited by Steedman); The Osage Tribe: Rite of the Wa-xo'-be (La Flesche).

Bulletin 88. Myths and Tales of the Southeastern Indians (Swanton).

Bulletin 90. Papago Music (Densmore).

Bulletin 91. Additional Studies of the Arts, Crafts, and Customs of the Guiana Indians, with special reference to those of Southeastern British Guiana (Roth).

Bulletin 93. Pawnee Music (Densmore).

DISTRIBUTION OF PUBLICATIONS

The distribution of the publications of the bureau has been continued under the charge of Miss Helen Munroe, assisted by Miss Emma B. Powers. Publications were distributed as follows:

Report volumes and separates	7,605
Bulletins and separates	11,890
Contributions to North American Ethnology	34
Miscellaneous publications	583
Total	20,112

This is an increase of 10,986 publications distributed, due to the fact that five more publications were distributed to the mailing list than in the previous year. The mailing list, after revision during the year, stands at 1,642.

ILLUSTRATIONS

Following is a summary of work accomplished in the illustration branch of the bureau under the supervision of Mr. De Lancey Gill, illustrator:

Photographs retouched and lettered and drawings made ready for engraving	874
Drawings prepared, including maps, diagrams, etc	53
Engravers' proofs criticized	690
Printed editions of colored plates examined at Government Printing Office	23,000
Correspondence attended to	125
Photographic laboratory work by Dr. A. J. Olmsted, National Museum, in cooperation with the Bureau of American Ethnology:	
Negatives	143
Prints	275
Films developed from field exposures	12

LIBRARY

The reference library has continued under the care of Miss Ella Leary, librarian, assisted by Mr. Thomas Blackwell. The library consists of 28,512 volumes, about 16,377 pamphlets, and several thousand unbound periodicals. During the year 591 books were accessioned, of which 112 were acquired by purchase and 479 by gift and exchange; also 200 pamphlets and 4,100 serials, chiefly the publications of learned societies, were received and recorded, of which only 112 were obtained by purchase, the remainder being received through exchange. The catalogue was increased by the addition of 1,400 cards. Many books were loaned to other libraries in Washington. In addition to the constant drafts on the library of the bureau, requisition was made on the Library of Congress during the year for an aggregate of 200 volumes for official use, and in turn the bureau library was frequently consulted by officers of other Government establishments, as well as by students not connected with the Smithsonian Institution.

While many volumes are still without binding, the condition of the library in this respect has greatly improved during the last few years; 431 volumes were bound during the year.

COLLECTIONS

100,592. Several thousand anthropological specimens and small collections of mammals, plants, mollusks, and minerals from various localities in Alaska, secured by Henry B. Collins, jr., during 1928. (3,730 specimens.)

102,768. Small collection of archeological objects gathered by Charles T. Earle at an aboriginal camp site at Shaws Point, Fla. (26 specimens.)

102,769. Two textile fragments collected in the Canyon de Chelly, Ariz., by Dr. W. H. Spinks. (2 specimens.)

102,896. Collection of 61 ethnological specimens secured from the Hupa Indians of California by E. G. Johnson. (61 specimens.)

103,344. Two specimens of sheet mica collected from unidentified mounds in Ohio by the late Dr. E. H. Davis and presented to the bureau by Miss Betsey B. Davis. (2 specimens.)

103,964. Pair of charms used by the Karuk Indians of northern California to ward off pains and bewitchments. Made by Mrs. Phoebe Maddux, of the Karuk Tribe. (2 specimens.)

105,865. Collection of ethnological objects gathered from the Hupa Indians of California by E. G. Johnson and purchased from him by the bureau. (27 specimens.)

PROPERTY

Office equipment was purchased to the amount of $292.70.

MISCELLANEOUS

The correspondence and other clerical work of the office has been conducted by Miss May S. Clark, clerk to the chief, assisted by Mr. Anthony W. Wilding, assistant clerk. Miss Mae W. Tucker, stenographer, assisted Dr. John R. Swanton in his work of compiling a dictionary of the Atakapa and compiled two catalogues of the manuscripts in the archives of the bureau—one arranged according to author and the other numerically. Mrs. Frances S. Nichols assisted the editor.

During the course of the year information was furnished by members of the staff in reply to numerous inquiries concerning the North American Indian peoples, both past and present, and the Mexican peoples of the prehistoric and early historic periods to the south. Various specimens sent to the bureau were identified and data on them furnished for their owners.

Personnel.—Mr. M. W. Stirling was appointed chief of the bureau August 1, 1928. Dr. J. Walter Fewkes retired as associate anthropologist of the bureau November 14, 1928.

Respectfully submitted.

M. W. Stirling, *Chief.*

Dr. C. G. Abbot,
Secretary, Smithsonian Institution.

APPENDIX 5

REPORT ON THE INTERNATIONAL EXCHANGE SERVICE

SIR: I have the honor to submit the following report on the operations of the International Exchange Service during the fiscal year ending June 30, 1929:

The appropriation made by Congress for the support of the Exchange Service for 1929 was $50,355, an increase of $3,500 over the amount for the preceding year. Of this increase, $2,147 was provided for in a deficiency bill to cover the additional sum required to meet the provisions of the Welch Act amending the classification act of 1923, $1,000 to meet the extra cost for freight, and $353 to advance to the next step in their respective grades those of the employees of the exchange office eligible for promotion.

The total number of packages handled was 620,485, an increase of 78,262 over the previous year. This is the second largest increase in the number of packages passing through the service in any one year since its organization in 1850. The greatest increase in packages was in 1927, when it was over 100,000. The total weight of the packages handled was 621,373 pounds, an increase of 27,252.

The number and weight of the packages of different classes are given in the following table:

	Packages		Weight	
	Sent	Received	Sent	Received
			Pounds	*Pounds*
United States parliamentary documents sent abroad	239,096		102,404	
Publications received in return for parliamentary documents		5,773		23,051
United States departmental documents sent abroad	183,576		152,696	
Publications received in return for departmental documents		5,698		23,671
Miscellaneous scientific and literary publications sent abroad	139,520		216,785	
Miscellaneous scientific and literary publications received from abroad for distribution in the United States		46,822		102,766
Total	562,192	58,293	471,885	149,488
Grand total	620,485		621,373	

It will be observed from the above table that many more packages are sent abroad than are received, yet the disparity is not as great as appears from the figures. Packages sent abroad in many

instances contain only a single publication, while those received in return often comprise several volumes. Furthermore, a number of foreign correspondents forward their publications directly to their destinations in this country by mail.

During the year there were shipped abroad 2,823 boxes, a decrease of 49 from the number sent last year, although the total weight of the consignments shipped to foreign countries was practically the same for the two years. Of the total number of boxes shipped abroad 604 contained full sets of United States official documents

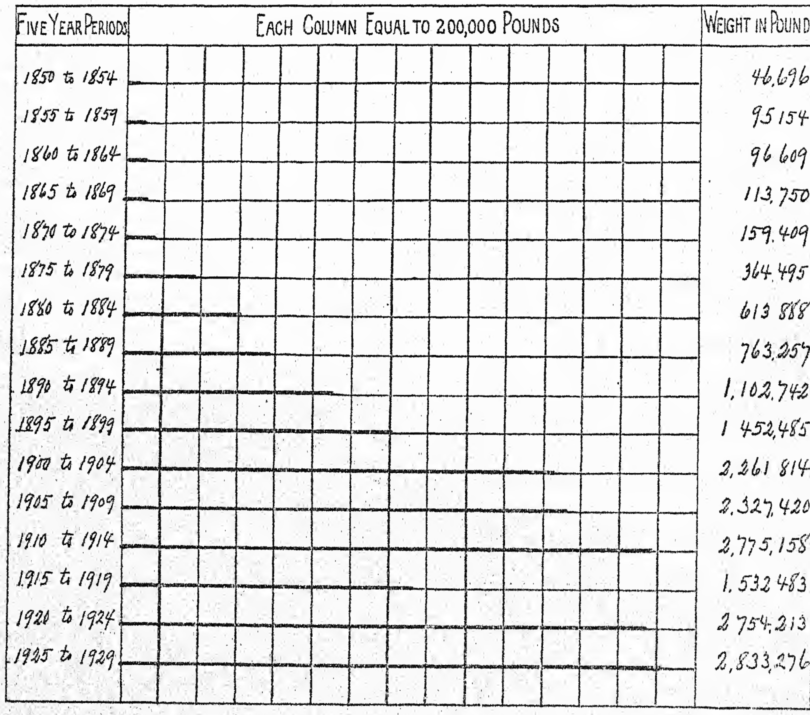


FIGURE 1.—Diagram showing the relative weight of packages transmitted through the International Exchange Service between the years 1850 and 1929, divided into periods of five years each

for foreign depositories and 2,219 included departmental and other publications for the depositories of partial sets and for miscellaneous establishments and individuals.

In addition to the forwarding of consignments to foreign exchange agencies in boxes, it is necessary, for the reasons given in previous reports, to mail a number of packages directly to their destinations. There were forwarded in this manner during the year 60,856 packages.

The number of boxes sent to each foreign country is given in the following table:

Consignments of exchanges forwarded to foreign countries

Country	Number of boxes	Country	Number of boxes
Argentina	57	Latvia	11
Austria	58	Mexico	11
Belgium	64	Netherlands	85
Brazil	40	New South Wales	37
Bulgaria	2	New Zealand	26
British Colonies	14	Norway	55
Canada	44	Palestine	106
Chile	25	Peru	21
China	91	Poland	45
Colombia	22	Portugal	24
Costa Rica	22	Queensland	31
Cuba	11	Rumania	24
Czechoslovakia	64	Russia	133
Denmark	49	South Australia	25
Egypt	19	Spain	38
Estonia	35	Sweden	69
Finland	14	Switzerland	77
France	174	Tasmania	23
Germany	330	Turkey	11
Great Britain and Ireland	382	Union of South Africa	36
Greece	4	Uruguay	20
Haiti	3	Venezuela	21
Honduras	2	Victoria	51
Hungary	35	Western Australia	23
India	54	Yugoslavia	16
Italy	102		
Japan	87	Total	2,823

For many years prior to 1926 the interchange of publications between China and the United States was conducted under the direction of the Shanghai Bureau of Foreign Affairs. The Chinese Bureau of Exchanges was under the direction of the Ministry of Education at Peking from May, 1926, to June, 1928, when operations were suspended owing to the reorganization of the Chinese Government. The Metropolitan Library, in which was then deposited the full series of United States governmental documents sent to China, temporarily took over the work of the bureau. The exchange work was carried on by that library until February, 1929, when a communication was received from the National Research Institute, 205 Avenue du Roi Albert, Shanghai, stating that the Nationalist Government had transferred the Bureau of International Exchanges from Peking to Shanghai and had placed the bureau under its direction. Shipments therefore have been made in care of the National Research Institute since March, 1929.

In June, 1925, the Egyptian Government, which had not at that time become a party to the Brussels convention, discontinued its exchange bureau in the Government Publications Office, and it was necessary to send packages intended for correspondents in Egypt directly to their destinations by mail. In June, 1927, as stated in the

report for that year, the Egyptian Government formally adhered to the Brussels convention and established as its agency the Bureau of Publications under the Ministry of Finances at Cairo. Complete arrangements for the taking over of the exchange work by that bureau, however, were not perfected until September, 1928, when shipments in boxes to Egypt were resumed.

A few days after the close of the fiscal year the Government printer of South Australia advised the Institution that his Government, at the invitation of the League of Nations, had established under his direction the South Australian Government Exchanges Bureau to take over the exchange work conducted for many years by the Public Library of South Australia.

FOREIGN DEPOSITORIES OF GOVERNMENTAL DOCUMENTS

There has been no increase in the number of sets of United States governmental documents forwarded to foreign depositories, the total number being 105. However, there has been a change in the number of depositories of the full and partial sets, two of the latter, those for Latvia and Rumania, having been increased to full sets. The number of full sets, therefore, is now 62 and partial sets 43.

At the request of the German Government the depository of American official documents has been changed from the Deutsche Reichstags-Bibliothek to the Reichstauschstelle im Reichsministerium des Innern, Berlin.

The partial set depository in Guatemala has been changed from the Secretary to the Government to the Secretaria de Relaciones Exteriores de la Republica de Guatemala; and the depository in Honduras from the Secretary of the Government to Ministerio de Relaciones Exteriores.

The depository of the full set of governmental documents sent to Italy has been changed from the Biblioteca Nazionale Vittorio Emanuele to the Ministero della Pubblica Istruzione, Viale del Re, Rome.

The Nationalist Government of China has changed the depository of United States official documents in that country from the Metropolitan Library in Peking to the Ministry of Foreign Affairs at Nanking.

A list of the foreign depositories is given below:

DEPOSITORIES OF FULL SETS

ARGENTINA: Ministerio de Relaciones Exteriores, Buenos Aires.

BUENOS AIRES: Biblioteca de la Universidad Nacional de La Plata, La Plata. (Depository of the Province of Buenos Aires.)

AUSTRALIA: Library of the Commonwealth Parliament, Canberra.
NEW SOUTH WALES: Public Library of New South Wales, Sydney.
QUEENSLAND: Parliamentary Library, Brisbane.
SOUTH AUSTRALIA: Parliamentary Library, Adelaide.
TASMANIA: Parliamentary Library, Hobart.
VICTORIA: Public Library of Victoria, Melbourne.
WESTERN AUSTRALIA: Public Library of Western Australia, Perth.
AUSTRIA: Bundesamt für Statistik, Schwarzenbergstrasse 5, Vienna I.
BELGIUM: Bibliothèque Royale, Brussels.
BRAZIL: Bibliotheca Nacional, Rio de Janeiro.
CANADA: Library of Parliament, Ottawa.
MANITOBA: Provincial Library, Winnipeg.
ONTARIO: Legislative Library, Toronto.
QUEBEC: Library of the Legislature of the Province of Quebec, Quebec.
CHILE: Biblioteca del Congreso Nacional, Santiago.
CHINA: Ministry of Foreign Affairs, Nanking.
COLOMBIA: Biblioteca Nacional, Bogotá.
COSTA RICA: Oficina de Depósito y Canje Internacional de Publicaciones, San José.
CUBA: Secretaría de Estado (Asuntos Generales y Canje Internacional), Habana.
CZECHOSLOVAKIA: Bibliothèque de l'Assemblée Nationale, Prague.
DENMARK: Kongelige Bibliotheket, Copenhagen.
EGYPT: Bureau des Publications, Ministère des Finances, Cairo.
ESTONIA: Riigiraamatukogu (State Library), Tallinn (Reval).
FRANCE: Bibliothèque Nationale, Paris.
PARIS: Préfecture de la Seine.
GERMANY: Reichstauschstelle im Reichsministerium des Innern, Berlin C 2.
BADEN: Universitäts-Bibliothek, Freiburg. (Depository of the State of Baden.)
BAVARIA: Bayerische Staatsbibliothek, Munich.
PRUSSIA: Preussische Staatsbibliothek, Berlin, N. W. 7.
SAXONY: Sächsische Landesbibliothek, Dresden—N. 6.
WURTEMBERG: Landesbibliothek, Stuttgart.
GREAT BRITAIN:
ENGLAND: British Museum, London.
GLASGOW: City Librarian, Mitchell Library, Glasgow.
LONDON: London School of Economics and Political Science. (Depository of the London County Council.)
GREECE: Bibliothèque Nationale, Athens.
HUNGARY: Hungarian House of Delegates, Budapest.
INDIA: Imperial Library, Calcutta.
IRISH FREE STATE: National Library of Ireland, Dublin.
ITALY: Ministero della Pubblica Istruzione, Rome.
JAPAN: Imperial Library of Japan, Tokyo.
LATVIA: Bibliothèque d'Etat, Riga.
MEXICO: Biblioteca Nacional, Mexico, D. F.
NETHERLANDS: Royal Library, The Hague.
NEW ZEALAND: General Assembly Library, Wellington.
NORTHERN IRELAND: Ministry of Finance, Belfast.
NORWAY: Universitets-Bibliotek, Oslo. (Depository of the Government of Norway.)

PERU: Biblioteca Nacional, Lima.
POLAND: Bibliothèque du Ministère des Affaires Etrangères, Warsaw.
PORTUGAL: Biblioteca Nacional, Lisbon.
RUMANIA: Academia Română, Bucharest.
RUSSIA: Shipments temporarily suspended.
SPAIN: Servicio del Cambio Internacional de Publicaciones, Cuerpo Facultativo de Archiveros, Bibliotecarios y Arqueólogos, Madrid.
SWEDEN: Kungliga Biblioteket, Stockholm.
SWITZERLAND: Bibliothèque Centrale Fédérale, Berne.
SWITZERLAND: Library of the League of Nations, Geneva.
TURKEY: Ministère de l'Instruction Publique, Angora.
UNION OF SOUTH AFRICA: State Library, Pretoria, Transvaal.
URUGUAY: Oficina de Canje Internacional de Publicaciones, Montevideo.
VENEZUELA: Biblioteca Nacional, Caracas.
YUGOSLAVIA: Ministère de l'Education, Belgrade.

DEPOSITORIES OF PARTIAL SETS

AUSTRIA:
  VIENNA: Wiener Magistrat.
BOLIVIA: Ministerio de Colonización y Agricultura, La Paz.
BRAZIL:
  MINAS GERAES: Directoria Geral de Estatistica em Minas, Bello Horizonte, Minas Geraes.
  RIO DE JANEIRO: Bibliotheca da Assemblea Legislativa do Estado, Nictheroy.
CANADA:
  ALBERTA: Provincial Library, Edmonton.
  BRITISH COLUMBIA: Legislative Library, Victoria.
  NEW BRUNSWICK: Legislative Library, Fredericton.
  NOVA SCOTIA: Provincial Secretary of Nova Scotia, Halifax.
  PRINCE EDWARD ISLAND: Legislative Library, Charlottetown.
  SASKATCHEWAN: Government Library, Regina.
BRITISH GUIANA: Government Secretary's Office, Georgetown, Demerara.
BULGARIA: Ministère des Affaires Étrangères, Sofia.
CEYLON: Colonial Secretary's Office (Record Department of the Library), Colombo.
DANZIG: Stadtbibliothek, Free City of Danzig.
DOMINICAN REPUBLIC: Biblioteca del Senado, Santo Domingo.
ECUADOR: Biblioteca Nacional, Quito.
FINLAND: Parliamentary Library, Helsingfors.
FRANCE:
  ALSACE-LORRAINE: Bibliothèque Universitaire et Régionale de Strasbourg, Strasbourg.
GERMANY:
  BREMEN: Senatskommission für Reichs- und Auswärtige Angelegenheiten.
  HAMBURG: Senatskommission für Reichs- und Auswärtige Angelegenheiten.
  HESSE: Landesbibliothek, Darmstadt.
  LÜBECK: President of the Senate.
  THURINGIA: Rothenberg-Bibliothek, Landesuniversität, Jena.
GUATEMALA: Secretaria de Relaciones Exteriores de la República de Guatemala.
HAITI: Secrétaire d'État des Relations Extérieures, Port au Prince.
HONDURAS: Ministerio de Relaciones Exteriores, Tegucigalpa.
ICELAND: National Library, Reykjavik.

INDIA:

BOMBAY: Undersecretary to the Government of Bombay, General Department, Bombay.

BURMA: Secretary to the Government of Burma, Education Department, Rangoon.

MADRAS: Chief Secretary to the Government of Madras, Public Department, Madras.

UNITED PROVINCES OF AGRA AND OUDH: University of Allahabad, Allahabad.

JAMAICA: Colonial Secretary, Kingston.

LIBERIA: Department of State, Monrovia.

LITHUANIA: Ministère des Affaires Étrangères, Kaunas (Kovno).

LOURENÇO MARQUEZ: Government Library, Lourenço Marquez.

MALTA: Minister for the Treasury, Valetta.

NEWFOUNDLAND: Colonial Secretary, St. John's.

NICARAGUA: Superintendente de Archivos Nacionales, Managua.

PANAMA: Secretaría de Relaciones Exteriores, Panama.

PARAGUAY: Sección Canje Internacional de Publicaciones del Ministerio de Relaciones Exteriores, Estrella 563, Asunción.

SALVADOR: Ministerio de Relaciones Exteriores, San Salvador.

SIAM: Department of Foreign Affairs, Bangkok.

STRAITS SETTLEMENTS: Colonial Secretary, Singapore.

INTERPARLIAMENTARY EXCHANGE OF OFFICIAL JOURNAL

The total number of establishments to which the daily issue of the Congressional Record is forwarded is 101, the same as last year.

The second convention concluded at Brussels in March, 1886, provided not only for the immediate exchange of the official journal but for the parliamentary annals and documents as well. Heretofore, however, the countries taking part in this interparliamentary exchange have restricted it to the official journal. During the year the French Chamber of Deputies, to which the Congressional Record has been forwarded for some time, proposed to this Government that the full provisions of the convention be entered into between France and the United States. This proposal was accepted, and there is now forwarded to the French Chamber direct by mail, immediately upon publication, the bills, reports, documents, and slip laws of both the Senate and House of Representatives.

There is given below a complete list of the countries now taking part in the immediate exchange, together with the names of the establishments to which the Record is forwarded:

DEPOSITORIES OF CONGRESSIONAL RECORD

ARGENTINA:

Biblioteca del Congreso Nacional, Buenos Aires.

Cámara de Diputados, Oficina de Información Parlamentaria, Buenos Aires.

Buenos Aires: Biblioteca del Senado de la Provincia de Buenos Aires, La Plata.

AUSTRALIA:
- Library of the Commonwealth Parliament, Canberra.
- New South Wales: Library of Parliament of New South Wales, Sydney.
- Queensland: Chief Secretary's Office, Brisbane.
- Western Australia: Library of Parliament of Western Australia, Perth.

AUSTRIA: Bibliothek des Nationalrates, Vienna I.

BELGIUM: Bibliothèque de la Chambre des Représentants, Brussels.

BOLIVIA: Biblioteca del H. Congreso Nacional, La Paz.

BRAZIL:
- Bibliotheca do Congresso Nacional, Rio de Janeiro.
- Amazonas: Archivo, Bibliotheca e Imprensa Publica, Manáos.
- Bahia: Governador do Estado de Bahia, São Salvador.
- Espirito Santo: Presidencia do Estado do Espirito Santo, Victoria.
- São Paulo: Diario Official do Estado de São Paulo, São Paulo.
- Sergipe: Director da Imprensa Official, Aracaju, Estado de Sergipe.

CANADA:
- Library of Parliament, Ottawa.
- Clerk of the Senate, Houses of Parliament, Ottawa.

CHINA: Metropolitan Library, Pei Hai, Peking.

COSTA RICA: Oficina de Depósito y Canje Internacional de Publicaciones, San José.

CUBA:
- Biblioteca de la Cámara de Representantes, Habana.
- Biblioteca del Senado, Habana.

CZECHOSLOVAKIA: Bibliothèque de l'Assemblée Nationale, Prague.

DANZIG: Stadtbibliothek, Danzig.

DENMARK: Rigsdagens Bureau, Copenhagen.

DOMINICAN REPUBLIC: Biblioteca del Senado, Santo Domingo.

DUTCH EAST INDIES: Volksraad von Nederlandsch-Indië, Batavia, Java.

EGYPT: Bureau des Publications, Ministère des Finances, Cairo.

ESTONIA: Riigiraamatukogu (State Library), Tallinn (Reval).

FRANCE:
- Chambre des Députés, Service de l'Information Parlementaire Etrangère. Paris.
- Bibliothèque du Sénat, au Palais du Luxembourg, Paris.

GERMANY:
- Deutsche Reichstags-Bibliothek, Berlin, N. W. 7.
- Anhalt: Anhaltische Landesbücherei, Dessau.
- Baden: Universitäts-Bibliothek, Heidelberg.
- Braunschweig: Bibliothek des Braunschweigischen Staatsministeriums, Braunschweig.
- Mecklenburg-Schwerin: Staatsministerium, Schwerin.
- Mecklenburg-Strelitz: Finanzdepartement des Staatsministeriums, Neustrelitz.
- Oldenburg: Oldenburgisches Staatsministerium, Oldenburg i. O.
- Prussia: Bibliothek des Abgeordnetenhauses, Prinz-Albrechtstrasse 5. Berlin, S. W. 11.
- Schaumburg-Lippe: Schaumburg-Lippische Landesregierung, Bücheburg.

GIBRALTAR: Gibraltar Garrison Library Committee, Gibraltar.

GREAT BRITAIN: Library of the Foreign Office, London.

GREECE: Library of Parliament, Athens.

GUATEMALA: Archivo General del Gobierno, Guatemala.

HAITI: Secrétaire d'État des Relations Extérieures, Port-au-Prince.

HONDURAS: Biblioteca del Congreso Nacional, Tegucigalpa.
HUNGARY: Bibliothek des Abgeordnetenhauses, Budapest.
INDIA: Legislative Department, Simla.
IRAQ: Chamber of Deputies, Baghdad, Iraq (Mesopotamia).
ITALY:
  Biblioteca del Senato del Regno, Rome.
  Biblioteca della Camera dei Deputati, Rome.
IRISH FREE STATE: Dail Eireann, Dublin.
LATVIA: Library of the Saeima, Riga.
LIBERIA: Department of State, Monrovia.
MEXICO: Secretaria de la Cámara de Diputados, Mexico, D. F.
  Aguascalientes: Gobernador del Estado de Aguascalientes, Aguascalientes.
  Campeche: Gobernador del Estado de Campeche, Campeche.
  Chiapas: Gobernador del Estado de Chiapas, Tuxtla Gutierrez.
  Chihuahua: Gobernador del Estado de Chihuahua, Chihuahua.
  Coahuila: Periódico Oficial del Estado de Coahuila, Palacio de Gobierno, Saltillo.
  Colima: Gobernador del Estado de Colima, Colima.
  Durango: Gobernador Constitucional del Estado de Durango, Durango.
  Guanajuato: Secretaría General de Gobierno del Estado, Guanajuato.
  Guerrero: Gobernador del Estado de Guerrero, Chilpancingo.
  Jalisco: Biblioteca del Estado, Guadalajara.
  Lower California: Gobernador del Distrito Norte, Mexicali, B. C., Mexico.
  Mexico: Gaceta del Gobierno, Toluca, Mexico.
  Michoacán: Secretaría General de Gobierno del Estado de Michoacán, Morelia.
  Morelos: Palacio de Gobierno, Cuernavaca.
  Nayarit: Gobernador de Nayarit, Tepic.
  Nuevo León: Biblioteca del Estado, Monterey.
  Oaxaca: Periódico Oficial, Palacio de Gobierno, Oaxaca.
  Puebla: Secretario General de Gobierno, Zaragoza.
  Queretaro: Secretaría General de Gobierno, Sección de Archivo, Queretaro.
  San Luis Potosi: Congreso del Estado, San Luis Potosi.
  Sinaloa: Gobernador del Estado de Sinaloa, Culiacan.
  Sonora: Gobernador del Estado de Sonora, Hermosillo.
  Tabasco: Secretaría General de Gobierno, Sección 3a, Ramo de Prensa. Villahermosa.
  Tamaulipas: Secretaría General de Gobierno, Victoria.
  Tlaxcala: Secretaría de Gobierno del Estado, Tlaxcala.
  Vera Cruz: Gobernador del Estado de Vera Cruz, Departamento de Gobernación y Justicia, Jalapa.
  Yucatán: Gobernador del Estado de Yucatán, Mérida, Yucatán.
NEW ZEALAND: General Assembly Library, Wellington.
NORWAY: Storthingets Bibliothek, Oslo.
PERU: Cámara de Diputados, Congreso Nacional, Lima.
POLAND: Ministère des Affaires Étrangères, Warsaw.
PORTUGAL: Biblioteca do Congresso da Republica, Lisbon.
RUMANIA:
  Bibliothèque de la Chambre des Députés, Bucharest.
  Ministère des Affaires Étrangères, Bucharest.
SPAIN:
  Biblioteca de la Asamblea Nacional, Madrid.
  Barcelona: Biblioteca de la Comisión Permanente Provincial de Barcelona, Barcelona.

Switzerland:
  Bibliothèque de l'Assemblée Fédérale Suisse, Berne.
  Library of the League of Nations, Geneva.
Syria:
  Ministère des Finances de la République Libanaise, Service du Matériel, Beirut.
  Governor of the State of Alaouites, Lattaquié.
Turkey: Turkish Grand National Assembly, Angora.
Union of South Africa:
  Library of Parliament, Cape Town, Cape of Good Hope.
  State Library, Pretoria, Transvaal.
Uruguay: Biblioteca de la Cámara de Representantes, Montevideo.
Venezuela: Cámara de Diputados, Congreso Nacional, Carácas.
Yugoslavia: Library of the Skupshtina, Belgrade.

FOREIGN EXCHANGE AGENCIES

South Australia has changed its exchange bureau from the Public Library at Adelaide to the Government Printing and Stationery Office, the name of the new bureau being the South Australian Government Exchanges Bureau.

The Austrian exchange agency, formerly the Bundesamt für Statistik, is now Internationale Austauschstelle, Bundeskanzleramt, Herrengasse 23, Vienna I.

The Nationalist Government of China has transferred its Bureau of International Exchange from Peking to Shanghai and made the bureau a part of the National Research Institute.

A list of the foreign exchange bureaus or agencies is given below. Most of those agencies forward consignments to the Smithsonian Institution for distribution in the United States.

LIST OF EXCHANGE AGENCIES

Algeria, via France.
Angola, via Portugal.
Argentina: Comisión Protectora de Bibliotecas Populares, Calle Córdoba 931, Buenos Aires.
Austria: Internationale Austauschstelle, Bundeskanzleramt, Herrengasse 23. Vienna I.
Azores, via Portugal.
Belgium: Service Belge des Echanges Internationaux, Rue des Longs-Chariots, 46, Brussels.
Bolivia: Oficina Nacional de Estadistica, La Paz.
Brazil: Servicio de Permutações Internacionaes, Bibliotheca Nacional, Rio de Janeiro.
British Colonies: Crown Agents for the Colonies, London.
British Guiana: Royal Agricultural and Commercial Society, Georgetown.
British Honduras: Colonial Secretary, Belize.
Bulgaria: Institutions Scientifiques de S. M. le Roi de Bulgarie, Sofia.
Canary Islands, via Spain.
Chile: Servicio de Canjes Internacionales, Biblioteca Nacional, Santiago.

CHINA: Bureau of International Exchange, National Research Institute, 205 Avenue du Roi Albert, Shanghai.

COLOMBIA: Oficina de Canjes Internacionales y Reparto, Biblioteca Nacional, Bogotá.

COSTA RICA: Oficina de Depósito y Canje Internacional de Publicaciones, San José.

CZECHOSLOVAKIA: Service Tchécoslovaque des Echanges Internationaux, Bibliothèque de l'Assemblée Nationale, Prague 1–79.

DANZIG: Amt für den Internationalen Schriftenaustausch der Freien Stadt Danzig, Stadtbibliothek, Danzig.

DENMARK: Kongelige Danske Videnskabernes Selskab, Copenhagen.

DUTCH GUIANA: Surinaamsche Koloniale Bibliotheek, Paramaribo.

ECUADOR: Ministerio de Relaciones Exteriores, Quito.

EGYPT: Bureau des Publications, Ministère des Finances, Cairo.

ESTONIA: Riigiraamatukogu (State Library), Tallinn (Reval).

FINLAND: Delegation of the Scientific Societies of Finland, Helsingfors.

FRANCE: Service Français des Échanges Internationaux, 110 Rue de Grenelle, Paris.

GERMANY: Amerika-Institut, Universitätstrasse 8, Berlin, N. W. 7.

GREAT BRITAIN AND IRELAND: Messrs. Wheldon & Wesley, 2, 3, and 4 Arthur St., New Oxford St., London W. C. 2.

GREECE: Bibliothèque Nationale, Athens.

GREENLAND, via Denmark.

GUATEMALA: Instituto Nacional de Varones, Guatemala.

HAITI: Secrétaire d'État des Relations Extérieures, Port-au-Prince.

HONDURAS: Biblioteca Nacional, Tegucigalpa.

HUNGARY: Hungarian Libraries Board, Budapest, IV.

ICELAND, via Denmark.

INDIA: Superintendent of Stationery, Bombay.

ITALY: R. Ufficio degil Scambi Internazionali, Ministero della Pubblica Istruzione, Rome.

JAMAICA: Institute of Jamaica, Kingston.

JAPAN: Imperial Library of Japan, Tokyo.

JAVA, via Netherlands.

KOREA: Government General, Seoul.

LATVIA: Service des Échanges Internationaux, Bibliothèque d'Etat de Lettonie, Riga.

LIBERIA: Bureau of Exchanges, Department of State, Monrovia.

LITHUANIA: Sent by mail.

LOURENÇO MARQUEZ, via Portugal.

LUXEMBURG, via Belgium.

MADAGASCAR, via France.

MADEIRA, via Portugal.

MOZAMBIQUE, via Portugal.

NETHERLANDS: International Exchange Bureau of the Netherlands, Royal Library, The Hague.

NEW SOUTH WALES: Public Library of New South Wales, Sydney.

NEW ZEALAND: Dominion Museum, Wellington.

NICARAGUA: Ministerio de Relaciones Exteriores, Managua.

NORWAY: Universitets-Bibliotek, Oslo.

PALESTINE: Hebrew University Library, Jerusalem.

PANAMA: Sent by mail.

PARAGUAY: Sección Canje Internacional de Publicaciones del Ministerio de Relaciones Exteriores, Estrella 563, Asuncion.

PERU: Oficina de Reparto, Depósito y Canje Internacional de Publicaciones, Ministerio de Fomento, Lima.

POLAND: Service Polonais des Echanges Internationaux, Bibliothèque du Ministère des Affaires Etrangères, Warsaw.

PORTUGAL: Secção de Trocas Internacionaes, Biblioteca Nacional, Lisbon.

QUEENSLAND: Bureau of Exchanges of International Publications, Chief Secretary's Department, Brisbane.

RUMANIA: Bureau des Échanges Internationaux, Institut Météorologique Central, Bucharest.

RUSSIA: Academy of Sciences, Leningrad.

SALVADOR: Ministerio de Relaciones Exteriores, San Salvador.

SIAM: Department of Foreign Affairs, Bangkok.

SOUTH AUSTRALIA: South Australian Government Exchanges Bureau, Government Printing and Stationery Office, Adelaide.

SPAIN: Servicio del Cambio Internacional de Publicaciones, Cuerpo Facultativo de Archiveros, Bibliotecarios y Arqueólogos, Madrid.

SUMATRA, via Netherlands.

SWEDEN: Kongliga Svenska Vetenskaps Akademien, Stockholm.

SWITZERLAND: Service Suisse des Échanges Internationaux, Bibliothèque Centrale Fédérale, Berne.

SYRIA: American University of Beirut.

TASMANIA: Secretary to the Premier, Hobart.

TRINIDAD: Royal Victoria Institute of Trinidad and Tobago, Port-of-Spain.

TUNIS, via France.

TURKEY: Robert College, Constantinople.

UNION OF SOUTH AFRICA: Government Printing Works, Pretoria, Transvaal.

URUGUAY: Oficina de Canje Internacional de Publicaciones, Montevideo.

VENEZUELA: Biblioteca Nacional, Caracas.

VICTORIA: Public Library of Victoria, Melbourne.

WESTERN AUSTRALIA: Public Library of Western Australia, Perth.

YUGOSLAVIA: Ministère des Affaires Étrangères, Belgrade.

Respectfully submitted.

C. W. SHOEMAKER,
Chief Clerk, International Exchange Service.

DR. CHARLES G. ABBOT,
Secretary, Smithsonian Institution.

APPENDIX 6

REPORT ON THE NATIONAL ZOOLOGICAL PARK

SIR: I have the honor to submit the following report on the operations of the National Zoological Park for the fiscal year ending June 30, 1929:

The appropriation made by Congress for the regular maintenance of the park was $182,050, and there was the usual allotment of $300 for printing and binding and an additional appropriation of $13,500 to cover the increase in salaries of the personnel under the Welch Act.

ACCESSIONS

Gifts.—The park this year has been the recipient of an unusual number of gifts of valuable animals. Notable among these are the several shipments of birds and animals obtained through Dr. H. C. Kellers, United States Navy, who was on duty with the Marines in Nicaragua. The animals were brought to Washington on a transport through the courtesy of the Navy Department. The specimens included large groups of spider monkeys, capuchins, and coatimundis; a flock of 6 sulphur-breasted toucans; a pair of curassows, many parrots, and several unusual birds and small mammals.

Dr. D. W. May sent from Porto Rico two rhinoceros iguanas, an unusual species in captivity. One specimen is doing well and promises to survive. Through Mr. Henry W. O'Malley, United States Commissioner of Fisheries, the park received a trio of northern fur seals from the Pribilof Islands, a species very rare in collections. From the New Zealand Government were received a pair of black swans and a pair of the rare paradise ducks. The New York Zoological Society sent a Prince Rudolph's blue bird of paradise and a Lawes's 6-plumed bird of paradise, part of the collection obtained by Mr. Crandall on the society's New Guinea expedition. Mrs. Emily C. Chadbourne presented a great black cockatoo; Mr. Harvey S. Firestone, jr., a potto from Liberia; Mr. J. F. Goldsby four Canada geese; and Mr. Richard Gordon six blue geese.

The most spectacular addition to the zoo in many years has been N'Gi, the gorilla. The animal was purchased with money remaining from the Smithsonian-Chrysler expedition funds. He weighed 40 pounds on arrival and has been the greatest attraction the zoo has

ever had. There were 40,000 visitors the first Sunday he was here, despite the coldness of the weather, and the following Sunday there were 20,000 more. Up to the present time he has been doing well and the officials of the park hope to keep him for a long time.

The officers of the United States Coast Guard patrol boat *Marion*, while engaged in survey work in Davis Straits, captured and brought to the zoo "Marian," a fine polar-bear cub. This is an especially valuable addition, because the other polar bears are now very aged.

A pair of Sitka deer presented by Mrs. Guy C. Chapin, Karheen, Alaska, through Mr. H. W. Terhune, of the Alaska Game Commission, are the first representatives of their species in the collection for many years.

The park is indebted to the office of the Chief Coordinator, which on numerous occasions has handled imports of animals and greatly facilitated the work of the park in getting them.

DONORS

Mrs. Anne Archbold, Washington, D. C., kinkajou.
Mr. Harry Bachrach, Washington, D. C., raccoon.
Mrs. Lena Bergland, Washington, D. C., grizzly coated cebus.
Mr. J. S. C. Boswell, Alexandria, Va., 7 snakes.
Mr. H. C. Breeden, Florida, raccoon.
Dr. Ira E. Briggs, Washington, D. C., alligator.
Mr. James F. Burgess, Washington, D. C., opossum.
Mr. Andrew J. Campbell, Washington, D. C., white-nosed guenon.
Mrs. E. C. Chadbourne, Washington, D. C., great black cockatoo.
Mrs. Guy C. Chapin, Karheen, Alaska, 2 Sitka deer.
Mr. Walter P. Chrysler, New York City, gorilla.
Mr. F. C. Craighead, Washington, D. C., 3 barred owls.
Mrs. N. M. Crowell, Washington, D. C., blue-headed parrot.
Dr. W. T. Dey, United States Navy, two chachalacas.
Mrs. W. J. Donovan, Washington, D. C., Texas armadillo.
Mr. A. A. Doolittle, Washington, D. C., king snake.
Mr. C. S. Fesser, Chevy Chase, Md., opossum.
Mr. Harvey S. Firestone, jr., Akron, Ohio, Bosman's potto.
Mr. J. F. Goldsby, Polson, Mont., 4 Canada geese.
Mrs. T. M. Goodwin, Scottsville, Va., white-throated capuchin.
Mr. Richard Gordon, Abbeville, La., 6 blue geese.
Mr. E. Hanson, Washington, D. C., coatimundi.
Mr. T. E. Henry, Port-au-Prince, Haiti, 4 scaled pigeons.
Mr. C. A. Higgins, Washington, D. C., green parrakeet.
President Hoover, White House, alligator.
Horne's Zoological Arena Co., Kansas City, Mo., lion.
Mr. J. B. Jones, Smithfield, Va., bald eagle.
Mr. Ellis Joseph, New York City, Humboldt's woolly monkey.
Mr. C. H. Keller, Washington, D. C., opossum.
Mr. William Kemble, Boston, Mass., white-faced capuchin.
Mr. Samuel Kress, Port Limon, Costa Rica, 3-toed sloth.
Mr. E. H. Lewis, Catalina Island, Calif., 6 valley quail, 4 mountain quail

Mrs. Mary Lincoln, Washington, D. C., canary.
Mr. M. C. Marseglia, Washington, D. C., canary.
Mr. D. W. May, Mayaguez, Porto Rico, 2 rhinoceros iguanas.
Mrs. McFarland, Hellier, Ky., golden eagle.
Mr. E. B. McLean, Washington, D. C., coatimundi.
Mrs. E. B. McLean, Washington, D. C., sooty mangabey.
Mrs. Elinor Messler, Miami, Fla., coatimundi.
Mrs. Mitchell, Washington, D. C., sooty mangabey.
Mr. M. C. Musgrave, Phoenix, Ariz., Gila monster,
New York Zoological Society, New York City, Prince Rudolph's blue bird of paradise, Lawes's 6-plumed bird of paradise.
New Zealand Government, 2 black swans, 1 pair paradise ducks, through J. Langridge.
Mrs. E. E. Patterson, Melbourne, Fla., diamond rattlesnake.
Mr. Harry A. Peters, Ballston, Va., Philippine macaque.
Policemen of seventh precinct, Washington, D. C., 9-banded armadillo.
Mr. Freeman Pollack, Washington, D. C., hog-nosed snake.
Mrs. W. L. Sherman, Washington, D. C., gray coatimundi.
Mr. J. W. Stohlman, Washington, D. C., great horned owl.
Mrs. C. F. Spradling, Athens, Tenn., banded rattlesnake, coot.
Mr. C. G. Taylor, Parksville, N. Y., Canada porcupine.
Mr. Frank Temple, Hyattsville, Md., 2 red-tailed hawks.
United States Bureau of Fisheries, through Mr. Henry O'Malley, 7 Pribilof Island finches, 3 northern fur seals.
United States Coast Guard, New London, Conn., polar bear.
United States Marine Corps, through Dr. H. C. Kellers, United States Navy, 3 margays, 2 kinkajous, 10 gray coatimundis, collared peccary, 3 speckled agoutis, 14 gray spider monkeys, 6 white-throated capuchins, caracara, 10 red-faced paroquets, 2 small green paroquets, 6 sulphur-breasted toucans, 2 curassows, 2 crab-eating raccoons, 45 tovi paroquets, gallinule, red-eared paroquet, 13 yellow-naped parrots, 4 opossums, tree opossum, 3 Petz' paroquets, troupial.
Mr. L. W. Walker, Hugo, Colo., 2 coyotes, 2 white-necked ravens, 2 burrowing owls.
Mrs. Mildred F. Williams, Washington, D. C., West Indian troupial.
Bobby Woods, Washington, D. C., black snake.
Mr. W. B. Wynkoop, Washington, D. C., Philippine monkey.

Births.—There were 58 mammals born and 41 birds hatched in the park during the year. These included the following:

Japanese macaque	1	Alpine ibex	1
Lion	4	Tahr	3
Leopard	3	American elk	1
Neumann's genet	2	Red deer	2
Raccoon	7	Mule deer	1
Llama	3	Barasingha	1
Wild boar	4	Japanese deer	4
Wart hog	4	Fallow deer	4
American bison	2	Trinidad agouti	2
Indian buffalo	1	Paca	1
Yak	1	Canada goose	4
Rocky Mountain sheep	3	White-cheeked goose	7
Mouflon	2	Night heron	12
Aoudad	1	Silver gull	18

The pair of lions presented to President Coolidge by the mayor and citizens of Johannesburg produced four cubs. The parents are still young and promise to become magnificent animals.

Each of the two pairs of leopards caught as adults by the Smithsonian-Chrysler expedition have bred both this year and last. The wart hogs last year gave birth to five young, which died, but this year four young were born and are thriving.

Purchase and exchange.—Among the more important specimens acquired by purchase and exchange have been a cheetah, to replace a pair lost last year; a pair of European wild boars, which have since bred; a lot of 14 lories; a pair of Orinoco geese; four species of tree ducks for the great flight cage in the bird house; a pair of Spix macaws; and two Kea parrots. As the available quarters are limited and crowded, there have been purchased only especially desirable species.

Removals.—Losses by death included one gibbon, which died of pneumonia; a rhinoceros hornbill; a striped hyena, which lived in the park from May 1, 1918, to September 27, 1928; a Malay tapir, which was received September 13, 1921, and died September 29, 1928; a red kangaroo, received in June, 1912, and died November 3, 1928.

Post-mortem examinations were made in most cases by the pathological division of the Bureau of Animal Industry. The following list shows the results of the autopsies:

CAUSES OF DEATH

MAMMALS

Marsupialia: Enteritis, 1; gastroenteritis, 1.

Carnivora: Pneumonia, 3; congestion of lungs, 1; enteritis, 4; gastroenteritis, 3; internal hemorrhage, 1; goiter, 1; accident, 1; no cause found, 1.

Pinnipedia: Gastritis, 1.

Primates: Pneumonia, 3; tuberculosis, 1; gastroenteritis, 1; hepatitis, 2; intestinal parasites, 1.

Artiodactyla: Pneumonia, 1; intestinal obstruction, 1; difficult parturition, 2; old age, 2; no cause found, 1.

Perissodactyla: Accident, 1.

Edentata: No cause found, 1.

BIRDS

Casuariiformes: Aspergillosis, 1.

Ciconiiformes: Tuberculosis, 1; congestion of lungs, 1; enteritis, 1.

Anseriformes: Congestion of lungs, 1.

Psittaciformes: Enteritis, 1; no cause found, 1.

Coraciiformes: Gastroenteritis, 1.

Passeriformes: Aspergillosis, 1.

ANIMALS IN THE COLLECTION JUNE 30, 1929

MAMMALS

MARSUPIALIA

Virginia opossum (*Didelphis virginiana*)	8
Flying phalanger (*Petaurus breviceps*)	2
Brush-tailed rock wallaby (*Petrogale penicillata*)	1
Great red kangaroo (*Macropus rufus*)	1
Wombat (*Phascolomys mitchelli*)	1

CARNIVORA

Kadiak bear (*Ursus middendorffi*)	2
Alaska Peninsula bear (*Ursus gyas*)	4
Kidder's bear (*Ursus kidderi*)	2
European bear (*Ursus arctos*)	8
Grizzly bear (*Ursus horribilis*)	1
Apache grizzly (*Ursus apache*)	1
Himalayan bear (*Selenarctos thibetanus*)	1
Black bear (*Euarctos americanus*)	4
Cinnamon bear (*Euarctos americanus cinnamomum*)	4
Glacier bear (*Euarctos emmonsii*)	1
Sun bear (*Helarctos malayanus*)	1
Polar bear (*Thalarctos maritimus*)	3
Dingo (*Canis dingo*)	2
Gray wolf (*Canis nubilus*)	7
Coyote (*Canis latrans*)	7
Albino coyote (*Canis latrans*)	1
California coyote (*Canis ochropus*)	1
Hybrid coyote (*Canis latrans-rufus*)	4
Black-backed jackal (*Thos mesomelas*)	1
Red fox (*Vulpes fulva*)	8
Silver-black fox (*Vulpes fulva*)	1
European fox (*Vulpes vulpes*)	1
Kit fox (*Vulpes velox*)	1
Gray fox (*Urocyon cinereoargenteus*)	3
Cacomistle (*Bassariscus astutus*)	2
Raccoon (*Procyon lotor*)	15
Florida raccoon (*Procyon lotor elucus*)	2
Gray coatimundi (*Nasua narica*)	9
Kinkajou (*Potos flavus*)	5
Mexican kinkajou (*Potos flavus aztecus*)	1
Tayra (*Tayra barbara*)	1
Skunk (*Mephitis nigra*)	3
Wolverine (*Gulo luscus*)	3
American badger (*Taxidea americana*)	2
Ratel (*Mellivora capensis*)	1
Florida otter (*Lutra canadensis vaga*)	1
Palm civet (*Paradoxurus hermaphroditus*)	1
Binturong (*Arctictis binturong*)	1
Egyptian mongoose (*Herpestes ichneumon*)	1
Aard-wolf (*Proteles cristatus*)	1
East African spotted hyena (*Crocuta crocuta germinans*)	1
Brown hyena (*Hyæna brunnea*)	2
African cheetah (*Acinonyx jubatus*)	1
Lion (*Felis leo*)	10
Bengal tiger (*Felis tigris*)	1
Manchurian tiger (*Felis tigris longipilis*)	3
Black leopard (*Felis pardus*)	1
East African leopard (*Felis pardus suahelicus*)	9
Serval (*Felis serval*)	1
East African serval (*Felis capensis hindei*)	2
Ocelot (*Felis pardalis*)	2
Brazilian ocelot (*Felis pardalis brasiliensis*)	1
Mexican puma (*Felis azteca*)	3
Indian caracal (*Lynx caracal*)	1
Abyssinian caracal (*Lynx caracal nubica*)	1
Bay lynx (*Lynx rufus*)	3
Bailey's lynx (*Lynx baileyi*)	1
Clouded leopard (*Neofelis nebulosa*)	1

PINNIPEDIA

California sea-lion (*Zalophus californianus*)	3
Northern fur seal (*Callotaria alascana*)	2
Leopard seal (*Phoca richardii var.*)	2
Harbor seal (*Phoca vitulina*)	1

RODENTIA

Woodchuck (*Marmota monax*)	5
Prairie dog (*Cynomys ludovicianus*)	11
Albino squirrel (*Sciurus carolinensis*)	2
American beaver (*Castor canadensis*)	2
East African porcupine (*Hystrix galeata*)	2
South African porcupine (*Hystrix africæ-australis*)	1
Malay porcupine (*Acanthion brachyurum*)	2
Central American paca (*Cuniculus paca virgatus*)	3
Trinidad agouti (*Dasyprocta rubrata*)	6
Speckled agouti (*Dasyprocta punctata*)	2
Guinea pig (*Cavia porcellus*)	10
Capybara (*Hydrochœrus hydrochæris*)	1

LAGOMORPHA

Domestic rabbit (*Oryctolagus cuniculus*)	10

PRIMATES

Zanzibar lemur (*Galago garnetti*)	1
Red-fronted lemur (*Lemur rufifrons*)	1
Black lemur (*Lemur macaco*)	1
Douroucouli (*Aotus trivirgatus*)	1
Gray spider monkey (*Ateles geoffroyi*)	4
Humboldt's woolly monkey (*Lagothrix humboldti*)	1
White-throated capuchin (*Cebus capucinus*)	8
Weeping capuchin (*Cebus apella*)	2
Chacma (*Papio porcarius*)	2
Anubis baboon (*Papio cynocephalus*)	6
Hamadryas baboon (*Papio hamadryas*)	1
Mandrill (*Papio sphinx*)	3
Drill (*Papio leucophæus*)	1
Moor monkey (*Cynopithecus maurus*)	3
Black ape (*Cynopithecus niger*)	1
Barbary ape (*Simia sylvanus*)	2
Japanese macaque (*Macaca fuscata*)	4
Brown macaque (*Macaca arctoides*)	2
Pig-tailed monkey (*Macaca nemestrina*)	1
Burmese macaque (*Macaca andamenensis*)	1
Rhesus monkey (*Macaca rhesus*)	12
Philippine macaque (*Macaca syrichta*)	3
Javan macaque (*Macaca mordax*)	5
Sooty mangabey (*Cercocebus fuliginosus*)	5
Green guenon (*Lasiopyga callitrichus*)	2
Vervet (*Lasiopyga pygerythra*)	1
Johnston's vervet (*Lasiopyga pygerythra johnstoni*)	2
Mozambique monkey (*Lasiopyga sp.*)	2
Sykes' guenon (*Lasiopyga albigularis*)	5
Mona guenon (*Lasiopyga mona*)	2
De Brazza's guenon (*Lasiopyga brazzæ*)	1
Lesser white-nosed guenon (*Lasiopyga petaurista*)	
Gray gibbon (*Hylobates leuciscus*)	
Chimpanzee (*Pan satyrus*)	
Orang-utan (*Pongo pygmæus*)	
Gorilla (*Gorilla gorilla*)	

ARTIODACTYLA

Wild boar (*Sus scrofa*)	4
Wart hog (*Phacochœrus æthiopicus*)	7
River hog (*Potamochœrus africanus*)	1
Collared peccary (*Pecari angulatus*)	3
Hippopotamus (*Hippopotamus amphibius*)	2
Pigmy hippopotamus (*Chœropsis liberiensis*)	1
Bactrian camel (*Camelus bactrianus*)	1
Arabian camel (*Camelus dromedarius*)	1
Guanaco (*Lama huanachus*)	2
Llama (*Lama glama*)	7
Reindeer (*Rangifer tarandus*)	4
Fallow deer (*Dama dama*)	14
White fallow deer (*Dama dama*)	1
Axis deer (*Axis axis*)	1
Hog deer (*Hyelaphus porcinus*)	5
Barasingha (*Rucervus duvaucelii*)	6
Burmese deer (*Rucervus eldii*)	1
Japanese deer (*Sika nippon*)	10
Red deer (*Cervus elaphus*)	13
Kashmir deer (*Cervus hanglu*)	2
Bedford deer (*Cervus xanthopygus*)	5
American elk (*Cervus canadensis*)	5
Costa Rican deer (*Odocoileus sp.*)	2
Guatemala deer (*Odocoileus sp.*)	1
Mule deer (*Odocoileus hemionus*)	1
Sitka deer (*Odocoileus columbianus sitkensis*)	2
Brindled gnu (*Connochætes taurinus*)	1
White-bearded gnu (*Connochætes taurinus albojubatus*)	2
Lechwe (*Onotragus leche*)	1
Inyala (*Tragelaphus angasi*)	1
Greater kudu (*Strepsiceros strepsiceros*)	1
Reed buck (*Redunca bohor*)	1
East African impalla (*Æpyceros melampus suara*)	2
Indian antelope (*Antilope cervicapra*)	1
Nilgai (*Boselaphus tragocamelus*)	2
Mountain goat (*Oreamnos americanus*)	2
Tahr (*Hemitragus jemlahicus*)	8
Alpine ibex (*Capra ibex*)	2
Aoudad (*Ammotragus lervia*)	4
Rocky Mountain sheep (*Ovis canadensis*)	12
Mouflon (*Ovis europæus*)	6
Greenland musk-ox (*Ovibos moschatus wardi*)	1
Zebu (*Box indicus*)	1
Yak (*Poëphagus grunniens*)	7
American bison (*Bison bison*)	15
Anoa (*Anoa depressicornis*)	1
Indian buffalo (*Bubalus bubalis*)	3
South African buffalo (*Synceros caffer*)	1

PERISSODACTYLA

Brazilian tapir (*Tapirus terrestris*)	1
Baird's tapir (*Tapirella bairdii*)	1
Mongolian horse (*Equus przewalskii*)	2
Mountain zebra (*Equus zebra*)	2
Chapman's zebra (*Equus quagga chapmani*)	2
Zebra-horse hybrid (*Equus grevyi-caballus*)	1
Zebra-ass hybrid (*Equus grevyi-asinus*)	1

PROBOSCIDEA

Abyssinian elephant (*Loxodonta africana oxyotis*)	1
Sumatran elephant (*Elephas sumatranus*)	1

XENARTHRA

Armadillo (*Dasypus novemcinctus*)	1

BIRDS

STRUTHIONIFORMES

South African ostrich (*Struthio australis*)	3
Somaliland ostrich (*Struthio molybdophanes*)	1
Nubian ostrich (*Struthio camelus*)	1

RHEIFORMES

Rhea (*Rhea americana*)	1

CASUARIIFORMES

Single-wattled cassowary (*Casuarius uniappendiculatus*)	1
Sclater's cassowary (*Casuarius philipi*)	1
Cassowary (*Casuarius sp.*)	1
Emu (*Dromiceius novæhollandiæ*)	2

CICONIIFORMES

American white pelican (*Pelecanus erythrorhynchos*)	9
European white pelican (*Pelecanus onocrotalus*)	2
Roseate pelican (*Pelecanus roseus*)	1
Australian pelican (*Pelecanus conspicillatus*)	2
Brown pelican (*Pelecanus occidentalis*)	5
California brown pelican (*Pelecanus californicus*)	5
Florida cormorant (*Phalacrocorax auritus floridanus*)	2
Brandt's cormorant (*Phalacrocorax penicillatus*)	1
Snake bird (*Anhinga anhinga*)	3
Great white heron (*Ardea occidentalis*)	1
Great blue heron (*Ardea herodias*)	2
Hybrid great blue and white heron (*Ardea herodias-occidentalis*)	1
Goliath heron (*Ardea goliath*)	1
Black-crowned night heron (*Nycticorax nycticorax nævius*)	91
Boatbill (*Cochlearius cochlearius*)	3
White-necked stork (*Dissura episcopus*)	1
Indian adjutant (*Leptoptilus dubius*)	2
Shoe-bill (*Balæniceps rex*)	1
Wood ibis (*Mycteria americana*)	1
Sacred ibis (*Threskiornis æthiopicus*)	1
Black-headed ibis (*Threskiornis melanocephalus*)	3
White ibis (*Guara alba*)	7
Scarlet ibis (*Guara rubra*)	3
European flamingo (*Phœnicopterus roseus*)	1

ANSERIFORMES

Mallard (*Anas platyrhynchos*)	26
Black duck (*Anas rubripes*)	7
Australian black duck (*Anas superciliosa*)	1
Gadwall (*Chaulelasmus streperus*)	12
European widgeon (*Mareca penelope*)	3
Baldpate (*Mareca americana*)	9
Green-winged teal (*Nettion carolinense*)	3
European teal (*Nettion crecca*)	4
Baikal teal (*Nettion formosum*)	5
Blue-winged teal (*Querquedula discors*)	1
Garganey (*Querquedula querquedula*)	6
Paradise duck (*Casarca variegata*)	2
Shoveller (*Spatula clypeata*)	1
Pintail (*Dafila acuta*)	11
Bahama pintail (*Dafila bahamensis*)	3
African pintail (*Dafila erythrorhyncha*)	2
Wood duck (*Aix sponsa*)	7
Mandarin duck (*Dendronessa galericulata*)	7

Canvasback (*Marila valisineria*)	7
European pochard (*Marila ferina*)	3
Redhead (*Marila americana*)	11
Tufted duck (*Marila fuligula*)	1
Lesser scaup duck (*Marila affinis*)	1
Greater scaup duck (*Marila marila*)	3
Rosy-billed pochard (*Metopiana peposaca*)	4
Egyptian goose (*Chenalopex ægyptiacus*)	2
Hawaiian goose (*Nesochen sandvicensis*)	2
Blue goose (*Chen cærulescens*)	11
White-fronted goose (*Anser albifrons*)	3
American white-fronted goose (*Anser albifrons gambeli*)	1
Bean goose (*Anser fabalis*)	2
Pink-footed goose (*Anser brachyrhynchus*)	1
Chinese goose (*Cygnopsis cygnoides*)	3
Orinoco goose (*Chenalopex jubata*)	1
Bar-headed goose (*Eulabeia indica*)	2
Canada goose (*Branta canadensis*)	17
Hutchins's goose (*Branta canadensis hutchinsii*)	3
White-cheeked goose (*Branta canadensis occidentalis*)	22
Cackling goose (*Branta canadensis minima*)	2
Brant (*Branta bernicla glaucogastra*)	9
Barnacle goose (*Branta leucopsis*)	3
Emperor goose (*Philacte canagica*)	1
Spur-winged goose (*Plectropterus gambensis*)	5
Muscovy duck (*Cairina moschata*)	3
Black-bellied tree duck (*Dendrocygna autumnalis*)	1
Fulvous tree duck (*Dendrocygna fulva*)	1
White-faced tree duck (*Dendrocygna viduata*)	1
Gray-breasted tree duck (*Dendrocygna discolor*)	2
West Indian tree duck (*Dendrocygna arborea*)	2
Eyton's tree duck (*Dendrocygna eytoni*)	3
Mute swan (*Cygnus gibbus*)	1
Whistling swan (*Cygnus columbianus*)	1
Black swan (*Chenopis atrata*)	8

FALCONIFORMES

Condor (*Vultur gryphus*)	1
California condor (*Gymnogyps californianus*)	3
Turkey vulture (*Cathartes aura*)	6
Black vulture (*Coragyps urubu*)	1
King vulture (*Sarcoramphus papa*)	2
Secretary bird (*Sagittarius serpentarius*)	1
Griffon vulture (*Gyps fulvus*)	1
Ruppell's vulture (*Gyps rueppelli*)	2
Northern eared vulture	2
African black vulture (*Torgos tracheliotus*)	1
Cinereous vulture (*Ægypius monachus*)	2
White-headed vulture (*Trigonoceps occipitalis*)	1
Caracara (*Polyborus cheriway*)	4
Wedge-tailed eagle (*Uroaëtus audax*)	2
Golden eagle (*Aquila chrysaëtos*)	7
Tawny eagle (*Aquila rapax*)	1
Bald eagle (*Haliæetus leucocephalus leucocephalus*)	10
Alaskan bald eagle (*Haliæetus leucocephalus alascanus*)	2
Red-tailed hawk (*Buteo borealis*)	10
Broad-winged hawk (*Buteo platypterus*)	1
East African chanting goshawk (*Melierax poliopterus*)	1
Sparrow hawk (*Falco sparverius*)	3
Osprey (*Pandion haliaëtus carolinensis*)	1

GALLIFORMES

Panama curassow (*Crax panamensis*)	2
Mexican curassow (*Crax globicera*)	2
Spix's wattled curassow (*Crax globulosa*)	3
Razor-billed curassow (*Mitu mitu*)	1
Crested guan (*Penelope boliviana*)	1
Chestnut-winged guan (*Ortalis garrula*)	1
Chachalaca (*Ortalis vetula*)	3
Vulturine guinea fowl (*Acryllium vulturinum*)	2
Reichenow's helmeted guinea fowl (*Numida mitrata reichenowi*)	10
Peafowl (*Pavo cristatus*)	7
Albino peafowl (*Pavo cristatus*)	4
Javan jungle fowl (*Gallus varius*)	3
Argus pheasant (*Argus giganteus*)	2
Silver pheasant (*Gennæus nycthemerus*)	2
Edward's pheasant (*Gennæus edwardsi*)	1
Golden pheasant (*Chrysolophus pictus*)	5
Lady Amherst's pheasant (*Chrysolophus amherstiæ*)	1
Ring-necked pheasant (*Phasianus torquatus*)	11
Migratory quail (*Coturnix coturnix*)	8
Pigmy quail (*Excalfactoria chinensis*)	4
Valley quail (*Lophortyx californica vallicola*)	3
Scaled quail (*Callipepla squamata*)	4
Crowned wood partridge (*Rollulus cristatus*)	1

GRUIFORMES

Florida gallinule (*Gallinula chloropus galeata*)	1
Purple gallinule (*Ionornis martinicus*)	1
East Indian gallinule (*Porphyrio calvus*)	1
Pukeko (*Porphyrio stanleyi*)	1
Black-tailed moor hen (*Microtribonyx ventralis*)	1
American coot (*Fulica americana*)	2
African moor hen (*Fulica cristata*)	4
African black crake (*Limnocrax flavirostra*)	1
Lesser rail (*Hypotænidia philippensis*)	2
South Island weka rail (*Ocydromus australis*)	1
Sandhill crane (*Megalornis mexicana*)	4
Little brown crane (*Megalornis canadensis*)	3
White-necked crane (*Megalornis leucauchen*)	1
Indian white crane (*Megalornis leucogeranus*)	1
Lilford's crane (*Megalornis lilfordi*)	1
Australian crane (*Mathewsena rubicunda*)	2
Demoiselle crane (*Anthropoides virgo*)	3
West African crowned crane (*Balearica pavonina*)	2
East African crowned crane (*Balearica regulorum gibbericeps*)	5
Common trumpeter (*Psophia crepitans*)	2
Green-winged trumpeter (*Psophia viridis*)	3
Kagu (*Rhynochetos jubatus*)	1

CHARADRIIFORMES

Ruff (*Philomachus pugnax*)	3
South American stone plover (*Œdicnemus bistriatus vocifer*)	1
Pacific gull (*Gabianus pacificus*)	1
Great black-backed gull (*Larus marinus*)	2
Western gull (*Larus occidentalis*)	6
Herring gull (*Larus argentatus*)	3
Silver gull (*Larus novæhollandiæ*)	48
Laughing gull (*Larus atricilla*)	2
Victoria crowned pigeon (*Goura victoria*)	1
Nicobar pigeon (*Calænas nicobarica*)	8
Bronze-wing pigeon (*Phaps chalcoptera*)	1

Bleeding-heart dove (*Gallicolumba luzonica*)	8
Wood pigeon (*Columba palumbus*)	6
Scaled pigeon (*Columba squamosa*)	3
Triangular spotted pigeon (*Columba guinea*)	3
Fiji Island pigeon (*Janthœnas vitiensis*)	1
Mourning dove (*Zenaidura macroura carolinensis*)	1
Mexican dove (*Zenaidura graysoni*)	1
White-fronted dove (*Leptotila fulviventris brachyptera*)	4
Necklace dove (*Spilopelia tigrina*)	1
Emerald-spotted dove (*Turtur chalcospilos*)	21
Ringed turtledove (*Streptopelia risoria*)	5
East African ring-necked dove (*Streptopelia capicola tropica*)	31
Masai mourning dove (*Streptopelia decipiens perspicillata*)	12
Zebra dove (*Geopelia striata*)	3
Bar-shouldered dove (*Geopelia humeralis*)	1
Cape masked dove (*Œna capensis*)	12
Inca dove (*Scardafella inca*)	1
Cuban ground dove (*Chæmepelia passerina aflavida*)	1
Pacific fruit pigeon (*Globicera pacifica*)	1
Bronze fruit pigeon (*Muscadivores ænea*)	1

PSITTACIFORMES

Kea (*Nestor notabilis*)	3
Violet-necked lory (*Eos variegata*)	2
Forsten's lorikeet (*Trichoglossus forsteni*)	3
Great black cockatoo (*Microglossus aterrimus*)	2
Roseate cockatoo (*Kakatoe roseicapilla*)	13
Bare-eyed cockatoo (*Kakatoe gymnopis*)	1
Leadbeater's cockatoo (*Kakatoe leadbeateri*)	2
White cockatoo (*Kakatoe alba*)	1
Sulphur-crested cockatoo (*Kakatoe galerita*)	6
Great red-crested cockatoo (*Kakatoe moluccensis*)	1
Mexican green macaw (*Ara militaris mexicana*)	2
Severe macaw (*Ara severa*)	1
Blue and yellow macaw (*Ara ararauna*)	7
Red and blue and yellow macaw (*Ara macao*)	4
Illiger's macaw (*Ara maracana*)	1
Spix's macaw (*Cyanopsittacus spixi*)	2
Hyacinthine macaw (*Anodorhynchus hyacinthinus*)	1
Blue-winged conure (*Pyrrhura picta*)	2
Nanday paroquet (*Nandayus nenday*)	6
Gray-breasted paroquet (*Myopsitta monachus*)	3
Petz's paroquet (*Eupsittula canicularis*)	7
Golden-crowned paroquet (*Eupsittula aurea*)	1
Weddell's paroquet (*Eupsittula weddellii*)	3
Golden paroquet (*Brotogeris chrysosema*)	1
Tovi paroquet (*Brotogeris jugularis*)	8
Yellow-naped parrot (*Amazona auropalliata*)	8
Mealy parrot (*Amazona farinosa*)	2
Orange-winged parrot (*Amazona amazonica*)	5
Blue-fronted parrot (*Amazona æstiva*)	1
Red-crowned parrot (*Amazona viridigenalis*)	3
Double-yellow-head parrot (*Amazona oratrix*)	4
Yellow-headed parrot (*Amazona ochrocephala*)	7
Panama parrot (*Amazona panamensis*)	1
Festive parrot (*Amazona festiva*)	3
Lesser white-fronted parrot (*Amazona albifrons nana*)	1
Santo Domingo parrot (*Amazona ventralis*)	3
Cuban parrot (*Amazona leucocephala*)	6
Maximilian's parrot (*Pionus maximiliani*)	1
Dusky parrot (*Pionus fuscus*)	1
Blue-headed parrot (*Pionus menstruus*)	1
Amazonian caique (*Pionites xanthomera*)	3
Hawk-head parrot (*Deroptyus accipitrinus*)	1
Yellow-fronted parrot (*Poicephalus flavifrons*)	1
East African brown parrot (*Poicephalus meyeri matschiei*)	2
Congo parrot (*Poicephalus gulielmi*)	1
Greater vasa parrot (*Coracopsis vasa*)	1
Red-faced love-bird (*Agapornis pullaria*)	5
Gray-headed love-bird (*Agapornis madagascariensis*)	8
Yellow-collared love-bird (*Agapornis personata*)	5
Fischer's love-bird (*Agapornis fischeri*)	4
Nyassa love-bird (*Agapornis lilianæ*)	9
Blue-crowned hanging paroquet (*Loriculus galgulus*)	1
Blue-bonnet paroquet (*Psephotus hæmatorrhous*)	1
Pennant's paroquet (*Platycercus elegans*)	1
Rosella paroquet (*Platycercus eximius*)	1
Crimson-winged paroquet (*Aprosmictus erythropterus*)	1
Ring-necked paroquet (*Conurus torquatus*)	1
Nepalese paroquet (*Conurus nepalensis*)	2
Long-tailed paroquet (*Conurus longicauda*)	1
Blossom-head paroquet (*Conurus cyanocephala*)	1
Grass paroquet (*Melopsittacus undulatus*)	10

CUCULIFORMES

Donaldson's turaco (*Turacus donaldsoni*)	1
Long-tailed cuckoo (*Eudynamis honorata*)	1

CORACIIFORMES

Jackson's hornbill (*Lophoceros jacksoni*)	1
Red-beaked hornbill (*Lophoceros erythrorhynchus*)	1
White-browed hornbill (*Anthracoceros malayanus*)	1
Plicated hornbill (*Rhytidoceros plicatus*)	1
Keel-billed toucan (*Ramphastos piscivorus*)	3
Ariel toucan (*Ramphastos ariel*)	1
Emin Pasha's barbet (*Trachyphonus emini*)	1
Barred owl (*Strix varia varia*)	14
Florida barred owl (*Strix varia alleni*)	1
Snowy owl (*Nyctea nyctea*)	1
Screech owl (*Otus asio*)	4
Great horned owl (*Bubo virginianus*)	10
Eagle owl (*Bubo bubo*)	1
American barn owl (*Tyto alba pratincola*)	3
African barn owl (*Tyto alba affinis*)	1

PASSERIFORMES

Red-billed hill-tit (*Liothrix luteus*)	18
Black-gorgeted laughing thrush (*Garrulax pectoralis*)	2
White-cheeked bulbul (*Molpastes leucogenys*)	1
Black-headed bulbul (*Molpastes hæmorrhous*)	3
White-eared bulbul (*Otocompsa leucotis*)	3
Red-eared bulbul (*Otocompsa jocosa*)	4
Piping crow-shrike (*Gymnorhina tibicen*)	1
White-necked raven (*Corvultur albicollis*)	1
American raven (*Corvus corax sinuatus*)	5
Australian crow (*Corvus coronoides*)	1
American crow (*Corvus brachyrhynchos*)	1

White-breasted crow (*Corvus albus*)	2
Red bird of paradise (*Paradisea sanguinea*)	2
Prince Rudolph's blue bird of paradise (*Paradisornis rudolphi*)	1
Lawes' bird of paradise (*Parotia lawesi*)	1
American magpie (*Pica pica hudsonia*)	1
Red-billed blue magpie (*Urocissa occipitalis*)	1
Yucatan jay (*Cissilopha yucatanica*)	2
Blue jay (*Cyanocitta cristata*)	2
Green jay (*Xanthoura luxuosa*)	2
Pileated jay (*Cyanocorax pileatus*)	2
Blue honey-creeper (*Cyanerpes cyaneus*)	1
Blue-winged tanager (*Tanagra cyanoptera*)	1
Blue tanager (*Thraupis cana*)	1
Giant whydah (*Diatropura progne*)	1
Paradise whydah (*Steganura paradisea*)	1
Shaft-tailed whydah (*Tetrænura regia*)	1
Red-crowned bishop bird (*Pyromelana sylvatica*)	4
Red-billed weaver (*Quelea quelea*)	5
Buffalo weaver (*Textor albirostris*)	2
Black-winged coral-billed weaver (*Textor niger nyassæ*)	25
Madagascar weaver (*Foudia madagascariensis*)	4
Black-headed weaver (*Hyphanturgus nigriceps*)	30
Southern masked weaver finch (*Quelea sanguinirostris intermedia*)	12
Emin's scaly-headed finch (*Sporopipes frontalis emini*)	25
St. Helena waxbill (*Estrilda astrilda*)	4
Orange-cheeked waxbill (*Estrilda melpoda*)	1
Rosy-rumped waxbill (*Estrilda rhodopygia*)	1
Blue-headed blue waxbill (*Uræginthus bengalus cyanocephalus*)	2
East African fire-throated finch (*Pytilia kirki*)	10
Strawberry finch (*Amandava amandava*)	20
Nutmeg finch (*Munia punctulata*)	50
White-headed nun (*Munia maja*)	1
Black-headed nun (*Munia atricapilla*)	2
Chestnut-breasted finch (*Munia castaneithorax*)	2
Java finch (*Munia oryzivora*)	27
Masked grass finch (*Poëphila personata*)	5
Diamond finch (*Steganopleura guttata*)	1
Zebra finch (*Tæniopygia castanotis*)	10
Cutthroat finch (*Amadina fasciata*)	14
Tanganyika cutthroat finch (*Amadina fasciata alexanderi*)	12
Red-headed finch (*Amadina erythrocephala*)	2
Yellow-headed marshbird (*Agelaius icterocephalus*)	1
Australian gray jumper (*Struthidea cinerea*)	1
European starling (*Sturnus vulgaris*)	9
Shining starling (*Lamprocorax metallicus*)	2
Southern glossy starling (*Lamprocolius pestis*)	4
Crested starling (*Galeopsar salvadorii*)	1
White-capped starling (*Heteropsar albicapillus*)	1
Indian mynah (*Acridotheres tristis*)	1
Crested mynah (*Æthiopsar cristatellus*)	1
Malay grackle (*Gracula javana*)	1
Bar-jawed troupia (*Gymnomystax melanicterus*)	1
West Indian troupial (*Icterus icterus*)	1
Hooded oriole (*Icterus cucullatus*)	1
Yellow-tailed oriole (*Icterus mesomelas*)	1
Purple grackle (*Quiscalus quiscula*)	1
Greenfinch (*Chloris chloris*)	3
Yellowhammer (*Emberiza citrinella*)	1
House finch (*Carpodacus mexicanus frontalis*)	2
San Lucas house finch (*Carpodacus mexicanus ruberrimus*)	2
Canary (*Serinus canarius*)	6
Little yellow serin (*Serinus icterus*)	15
Gray singing finch (*Serinus leucopygius*)	9
White-throated sparrow (*Zonotrichia albicollis*)	1
San Diego song sparrow (*Melospiza melodia cooperi*)	2
Coastal pale-bellied sparrow (*Passer griseus suahelicus*)	20
Saffron finch (*Sicalis flaveola*)	4
Guiana blue grosbeak (*Cyanocompsa cyanoides*)	1
Chinese grosbeak (*Eophona migratoria sowerbyi*)	1
Red-crested cardinal (*Paroaria cucullata*)	3

REPTILES

Alligator (*Alligator mississipiensis*)	26
Broad-nosed crocodile (*Osteolæmus tetraspis*)	6
Horned toad (*Phrynosoma cornutum*)	4
Gila monster (*Heloderma suspectum*)	8
Beaded lizard (*Heloderma horridum*)	2
Scaly-tailed lizard (*Uromastix hardwicki*)	4
Green lizard (*Lacerta viridis*)	2
Egyptian monitor (*Varanus niloticus*)	1
West Indian Iguana (*Cyclura cornuta*)	2
African sand-boa (*Eryx*)	2
Indian sand-boa (*Eryx*)	2
Ball python (*Python regius*)	1
Rock python (*Python molurus*)	2
Regal python (*Python reticulatus*)	1
African python (*Python sebæ*)	9
Anaconda (*Eunectes murinus*)	1
Dog-headed boa (*Corallus caninus*)	2
Black snake (*Coluber constrictor*)	5
Corn snake (*Elaphe guttata*)	1
Chicken snake (*Elaphe 4-lineatus*)	1
Pine snake (*Pituophis melanoluecus*)	2
King snake (*Lampropeltis getulus*)	2
Hog-nosed snake (*Heterodon platyrhinos*)	1
Water snake (*Natrix sipedon*)	1
Black-necked spitting cobra (*Naja nigricollis*)	1
Copperhead (*Agkistrodon mokasen*)	5
Florida rattlesnake (*Crotalus adamanteus*)	2
Western diamond rattlesnake (*Crotalus atrox*)	1
Banded rattlesnake (*Crotalus horridus*)	3
Snapping turtle (*Chelydra serpentina*)	2
Florida snapping turtle (*Chelydra osceola*)	1
African snake-necked terrapin (*Pelomedusa galeata*)	40
Australian snake-necked terrapin (*Chelodina longicollis*)	3
Musk turtle (*Sternotherus odoratus*)	1
Mexican musk turtle (*Kinosternon sonoriense*)	1
South American musk turtle (*Kinosternon scorpioides*)	5
Pennsylvania musk turtle (*Kinosternon subrubrum*)	2
Wood turtle (*Clemmys insculpta*)	2
Leprous terrapin (*Clemmys leprosa*)	1
Blanding's terrapin (*Emys blandingii*)	2
European pond turtle (*Emys orbicularis*)	3
South American terrapin (*Nicoria punctularia*)	1
Reeves turtle (*Geoclemys reevesi*)	1
Loochoo turtle (*Geoemyda spengleri*)	1

Painted turtle (*Chrysemys picta*)	2
Western painted turtle (*Chrysemys belli*)	1
Gopher tortoise (*Gopherus polyphemus*)	1
Duncan Island tortoise (*Testudo ephippium*)	3
Indefatigable Island tortoise (*Testudo porteri*)	1
Albermarle Island tortoise (*Testudo vicina*)	2
Angulated tortoise (*Testudo angulata*)	1
Leopard tortoise (*Testudo pardalis*)	6
Agassiz's tortoise (*Testudo agassizii*)	1
Berlandier's tortoise (*Testudo berlandieri*)	1
Soft-shelled tortoise (*Testudo loveridgei*)	8
Chicken turtle (*Deirochelys reticularia*)	1

BATRACHIANS

African smooth-clawed frog (*Xenopus mulleri*)	28
Giant salamander (*Megalobatrachus japonicus*)	2
Horned frog (*Ceratophrys cornuta*)	2
Marbled newt (*Triton marmorata*)	2

Statement of the collection

	Mammals	Birds	Reptiles and batrachians	Total
Presented	82	136	12	230
Born	58	41		99
Received in exchange	13	55		68
Purchased	17	43	20	80
On deposit	1		1	2
Total	171	275	33	479

SUMMARY

Animals on hand July 1, 1928	2, 273
Accessions during the year	479
Total animals handled	2, 752
Deduct loss (by death, return of animals, and exchange)	541
	2, 211

Status of collection

	Species	Individuals
Mammals	174	523
Birds	343	1, 461
Reptiles and batrachians	62	227
Total	579	2, 211

It is planned to erect the reptile house on the site of the old bird house, and this necessitates the razing of the old building, which has been used up to now as a storage house for animals and birds for which there were no other quarters. The destruction of this building will reduce the exhibition space so much that no attempt has been made to enlarge the collection, but rather to select, as replacements for animals and birds that have been lost, only especially desirable species. The result has been that the collection is unusually rich in rare and interesting forms. Exchanges of numerous common species for one or two rarities have been made. These exchanges have been advantageous in reducing congestion as well as improving the quality of the collection.

VISITORS

The estimated attendance as recorded in the daily reports of the park shows considerable increase over the preceding year and included visitors from every State in the Union.

Attendance by months was as follows:

1928		1929	
July	236, 971	January	64, 650
August	196, 200	February	105, 700
September	265, 550	March	366, 500
October	211, 550	April	295, 339
November	78, 050	May	275, 350
December	184, 100	June	248, 750
		Total for year	2, 528, 710

The attendance of organized classes of students was 30,886 from 497 different schools.

IMPROVEMENTS

During the year the work on the exterior of the bird house has been completed, outdoor cages have been constructed, and an attractive approach made to the building. Snow guards have been put on the skylights and the area in the rear of the building has been paved. In connection with this house it was necessary to lay 285 feet of pipe to a culvert.

The lion house and the antelope house have had their roofs recovered, in part with asphalt shingles, and also new gutters installed. It was also necessary during the year to put plastic coating on the roof of the hay shed, the old elephant house, the old bird house, the zebra house, the property house, and the buffalo shed. One of the cages at the old bear yard has been renovated. The office has been painted and redecorated for the first time in 26 years.

Having received a number of suggestions in regard to the bridle paths throughout the park, several consultations were held with those interested in riding and their suggestions followed out as closely as possible in altering these paths.

An appropriation of $220,000 has been made for the construction of a reptile house during the fiscal year 1930, and considerable work has been done on planning this building, which will, when completed, enable us to extend the collection to include reptiles, batrachians, and insects. This building will fill a very great need at the park.

In connection with the construction of the reptile house, the Smithsonian Institution, from its private funds, sent the director of the park and Mr. A. L. Harris, municipal architect, to Europe to study certain zoos. Special attention was given to the planning and construction of reptile houses, but other features were studied and much

information obtained which will be valuable in the development of our own zoo.

In all, 20 zoos were visited, in the following cities: London, Hanover, Hamburg, Copenhagen, Berlin, Dresden, Leipzig, Halle, Vienna, Budapest, Munich, Nuremberg, Frankfort, Cologne, Dusseldorf, Elberfeld, Antwerp, Amsterdam, Rotterdam, and Stellingen.

In London we attended the centenary of the London Zoo, where a notable group of zoologists, including many continental and some American delegates, were gathered. They were entertained by the London Zoological Society at a meeting and later at a memorable dinner in the Zoological Gardens. In all of the zoos visited we were shown the greatest courtesy and given much friendly aid, and by working together on the steamer on the return trip much time was saved in getting together preliminary plans for the reptile house. It is interesting to note that we did not see in Europe a single zoo that impressed us unfavorably. They are all thriving institutions and in nearly all of them new buildings are being added. The collections invariably were excellent.

NEEDS OF THE ZOO

The most urgent need at the present time is an exhibition building for apes, lemurs, and small mammals. There are now almost no quarters for small mammals. These come into the zoo sometimes in great numbers as gifts and include some of the most interesting of all animals. The few that it is possible to exhibit are quartered unsatisfactorily in the monkey house. The great apes, of which the park has a valuable collection, are so placed that it is often impossible for visitors to see them, whereas in a new building they would be housed in modern hygienic quarters, away from the other monkeys and chance of infection. Tentative plans for such a building have been made, and the cost is estimated at $225,000. This building, like the new reptile house, will provide facilities for exhibiting groups of animals for which up to now there has been no place at all.

In our entire building program, which includes besides the above building a pachyderm house, an antelope, buffalo, and wild-cattle house, the completion of the bird house, and the addition of various open-air cages, we are asking only for equipment that practically all modern zoos already possess—simply the necessary facilities of a modern zoological park.

Respectfully submitted.

W. M. Mann, *Director*.

Dr. Charles G. Abbot,
Secretary, Smithsonian Institution.

APPENDIX 7

REPORT ON THE ASTROPHYSICAL OBSERVATORY

SIR: I have the honor to submit the following report on the activities of the Astrophysical Observatory for the fiscal year ended June 30, 1929:

PLANT AND OBJECTS

This observatory operates regularly the central station at Washington and two field stations for observing solar radiation on Table Mountain, Calif., and Mount Montezuma, Chile. By arrangement with the National Geographic Society, the director of the observatory has charge of the cooperating solar radiation station of the society on Mount Brukkaros, South West Africa. In addition, the observatory controls a station on Mount Wilson, Calif., where occasional expeditions are sent for special investigations.

The principal aim of the observatory is the exact measurement of the intensity of the radiation of the sun as it is at mean solar distance outside the earth's atmosphere. This is ordinarily called the solar constant of radiation, but the observations of past years by this observatory have proved it variable. As all life as well as the weather depends on solar radiation, the observatory has undertaken the continued measurement of solar variation on all available days. These measurements have now continued all the year round for 11 years, but should continue at least 11 years more to cover the Hale 22.6-year solar cycle. In addition to this principal object, the observatory undertakes spectroscopic researches on radiation and absorption of atmospheric constituents, radiation of special substances such as water vapor, ozone, carbonic-acid gas, liquid water and others, and the radiation of the other stars as well as of the sun.

WORK AT WASHINGTON

Continuous series of solar observations having been made as hitherto at several field stations on desert mountains in distant lands, these observations have been critically studied and prepared for publication at Washington. Several new investigations based on these observations have been made and published and we have carried

on the preparation and standardization of apparatus. Details follow.

(*a*) *Periodicities in solar variation.*—Observations at Montezuma, in Chile, had been reduced to a consistent and definitive system several years since. This system requires no computations beyond those which the observers make regularly in the field. Telegrams in code are received daily from Montezuma, and when decoded are communicated to the United States Weather Bureau, which publishes on the Washington daily weather map the solar constant value observed 24 hours previously at Montezuma.

In November, 1928, Doctor Abbot assembled the monthly mean solar constant values of 101 consecutive months ending with October, 1928, and plotted them in the form of a curve. This curve Dr. Dayton C. Miller, of Cleveland, was kind enough to analyze by means of his ingenious and accurate machine, so as to bring out the first 30 harmonic constituents, which, combined, approximately represent the original curve.

From a previous analysis of 77 months, made in 1926, it had appeared that periods of about 26, 15, and 11 months and the submultiples of these periods were all the periods under 26 months that seemed to have continuous existence in the solar variation. Accordingly, the interval of 101 months had been purposely chosen as nearly a common multiple, so that if these periods were still persistent they might be brought out as approximately the fourth, the seventh, and the ninth harmonics, with their overtones.

Figure 2 shows the result of this analysis. The zigzag line A represents the original monthly mean of observations, and the 30 sinuous curves below are the harmonics. Until a longer interval of observation shall be available for analysis, it is not considered desirable to discuss periodicities longer than $\frac{101}{4}$ months. The reader will perceive that if we therefore neglect the march of the first, second, and third harmonics, the fourth, its overtones the eighth, twelfth, and sixteenth; the seventh, its overtones the fourteenth, twenty-first, and twenty-eighth; and the ninth and its approximate overtones the nineteenth and twenty-seventh are really the most prominent features, whereas some of the other harmonics, such as the fifth, sixth, tenth, eleventh, thirteenth, seventeenth, eighteenth, twentieth, twenty-fourth, twenty-sixth, and twenty-ninth, not included in these three series of overtones, nearly vanish. Indeed, apart from those named in connection with the fourth, the seventh, and the ninth, only the twelfth, fifteenth, twenty-third, and twenty-fifth seem to be of appreciable significance. This suggests that the third and its overtones may also have real significance. It is of great

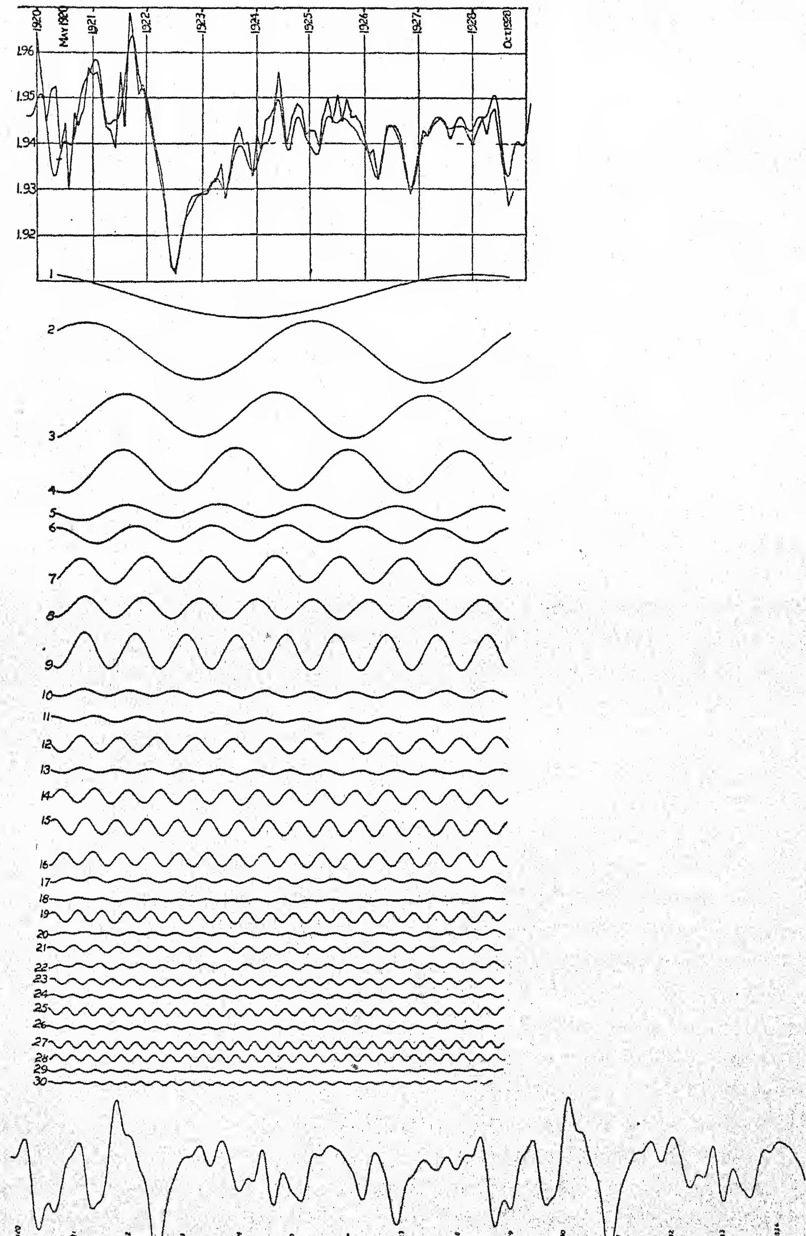


FIGURE 2.—Periodicities in solar variation

interest to note that the periods corresponding to the fourth, the seventh, and the ninth harmonics, which we find so well marked in solar variation, have also been particularly noted by students of the march of weather and crop phenomena.

Assuming that the harmonics from the fourth to the thirtieth represent all the real regular periodicities in the variation of solar radiation, the curve B, at the foot of the diagram, which is their summation, represents the march of this periodic part of solar variation. Continuing it to cover the years 1929, 1930, and 1931, we are led to anticipate features of uncommon interest in the march of solar variation in the period just approaching. It will, indeed, be exceedingly interesting to see to what degree this forecast is verified.

(*b*) *Reduction of Table Mountain observations.*—Observations at Table Mountain, Calif., which have continued since December, 1925, have been critically studied at great length during the past year by Mr. Fowle and the computers. Mr. Fowle has considered that the results might be affected by three variable atmospheric elements—the water vapor, the haze, and the ozone which occurs in the very high atmosphere. It was easy to arrange the data in groups corresponding to gradual increase of quantities of atmospheric water vapor, for this vapor is readily measured and expressed as total precipitable water by Fowle's method which he worked out from spectroscopic study in the laboratory many years ago. By such statistical arrangement, corrections for precipitable water were sought to be obtained.

However, there is one obstacle depending on the contemporaneous real variability of the sun which hinders immediate estimation of water-vapor influence. True, this solar variability might have been eliminated by employing the definitive results of Montezuma, but we avoided this procedure, since, in the opinion of some, it might not have left the Table Mountain observations fully independent. Accordingly, the solar variation was roughly estimated from Table Mountain pyrheliometry alone, after the method referred to in my report for 1926, page 116. Allowance was thus made for the solar variation before determining the water-vapor effect.

When these steps had been taken it became clear that a sudden increase of the Table Mountain solar constant values had been indicated about August 12, 1927. This change of scale continued with apparently increasing departures thereafter. No parallel result having been noted at Montezuma, every contributary element of the measurements at Table Mountain was investigated to learn the source of the discrepancy. It was soon found that the change was due to a large change in the scale of pyranometer measurements of the brightness of the sky near the sun. Yet redeterminations of the constants of the pyranometer itself by observing solar radiation with

it gave excellent agreement with previous values. Very numerous experiments and comparisons were made at Table Mountain in the effort to trace the cause of the discrepancy. These were without result until September, 1928, when Doctor Abbot visited the station and observed that portions of the vestibule of the instrument had become shiny by handling. Hence sunlight in addition to sky light was reaching the sensitive measuring strip. By reblackening the limiting diaphragm nearly all of this error was removed.

It was now necessary to perform a great mass of statistical computing in order to determine the magnitude of the pyranometer error at different dates. Fortunately, an error of 20 per cent in pyranometry makes but 1 per cent error in the solar constant, so that no great accuracy of determining the error was required. Hence it appeared sufficient to collect all the pyranometer values of each month, arranging them in orders of atmospheric humidity, air-mass, and pyrheliometer value, and to compare the mean pyranometer values of corresponding months in successive years, as well as the values in nearly identical sky conditions throughout each year.

It soon became clear that no change in the instrument had occurred prior to early August, 1927. At that time there had been many experimental comparisons involving handling of the vestibule, which had done the damage and led to the sudden change. Afterwards many more comparisons were made to find the trouble, and these had aggravated it. After much work it became possible to determine a set of sufficiently exact corrections to the pyranometry of 1927 and 1928 suitable to each of the 13 months during which they were needed. These studies were made on Table Mountain observations exclusively, so that they introduced no element of dependence on Montezuma.

To prevent a future mischance of this kind, imperative orders were issued to all stations as to the handling of instruments, and standard instruments, for comparison purposes only, were added to the equipment, with instructions to make fairly frequent comparisons between these and the instruments in use.

(*c*) *Atmospheric ozone.*—Mr. Fowle, having become impressed that the variations recently investigated by Dobson in the quantity of atmospheric ozone might very possibly affect the observed solar constant, made a fruitful investigation of the absorption of ozone in the yellow and green of the solar spectrum.[1] He found that this absorption, though small, is clearly and quantitatively indicated by means of the atmospheric transmission coefficients obtained in the application of the fundamental long method of solar constant determination invented by Langley. As we frequently employ this

[1] Published in Smithsonian Misc. Coll., vol. 81, No. 11, 1929.

method at all stations as a check on the short method in daily use, Fowle was able to determine the atmospheric ozone at Calama, Montezuma, Harqua Hala, and Table Mountain on very many occasions since the year 1920.

It proved, harmoniously to what Dobson had found, that the ozone above Mount Montezuma is meager and nearly invariable in quantity, but that above Harqua Hala and Table Mountain it is much more plentiful and very variable. Having compared the variations of monthly mean ozone values with the Table Mountain observations of corresponding variations of solar constant values, Mr. Fowle found a strong correlation between them. As the yearly march of the monthly mean ozone values at these northern stations appears to be a terrestrial phenomenon, a fact entirely harmonious to those well established by Dobson, it seemed entirely legitimate to introduce a solar constant correction, statistically determined, to allow for ozone in much the same way as for water vapor, for the Harqua Hala values.

(*d*) *Concordant results of Table Mountain and Montezuma.*—This having been done, and the water-vapor and haziness corrections having been applied, it was found that the absolutely independent final values of the solar constant determined at two stations 4,000 miles apart (viz, Table Mountain, 7,500 feet high, in California, and Montezuma, 9,000 feet high, in Chile) march with gratifying accord. For the *ratios* of the values determined at the two stations show no appreciable indication of a *yearly* range, although winter at the one station corresponds with summer at the other. Furthermore, the total *range* of straggle of nine-tenths of the *daily* ratios of these independent values *does not exceed 1.1 per cent.* This involves the conclusion that the *total range of accidental error* at a single station seldom exceeds 0.8 per cent, and therefore the probable value of the accidental determination of a single day at one station is less than 0.3 per cent. This being so, we are prepared to expect that both stations, though wholly independent, must concur within narrow limits in their determination of the sun's variation.

(*e*) *Preparation of Volume V of the Annals.*—With this gratifying conclusion reached in the final discussion of the results of two independent solar observing stations remote from each other, a point seems to be reached where it is proper to publish Volume V of the Annals of the Astrophysical Observatory, to contain the numerous observations obtained since the year 1920. Doctor Abbot has been engaged on the preparation of this text, and it is hoped that the volume will be ready to publish in the fiscal year ending June, 1931, thus including a full decade of observations.

(*f*) *Other work at Washington.*—As usual, many instruments have been constructed at Washington for research purposes. These in-

clude a number of silver-disk pyrheliometers, prepared at the expense of the private funds of the Institution, but standardized against the standard instruments of the Astrophysical Observatory, and sold at cost to research institutions of various lands.

Mr. Aldrich has assumed charge of the instrument making and standardizing. He has also continued work on the fruitful investigation of the radiation and cooling of the human body, referred to last year. In addition he has assisted in reducing solar-constant observations, and has attended to the considerable correspondence on physical and astronomical matters.

FIELD WORK

(*a*) *At Mount Wilson, Calif.*—Doctor Abbot spent the months of July, August, and part of September, 1928, at Mount Wilson, Calif., where he was assisted by Mr. Freeman. Besides improving the solar cooker to greatly increased efficiency, two considerable researches were carried through. The first of these is the repetition of the bolometric determination of positions of solar and terrestrial absorption lines and bands in the infra-red solar spectrum. This had formed the main subject of Volume I of the Annals of the Astrophysical Observatory. As photography has not as yet reached far beyond the extreme red of the spectrum, the best means of observing these interesting lines and bands of the infra-red lies in measuring the cooling which attends them. For this purpose a well-dispersed spectrum is caused to march slowly over a sensitive linear bolometer strip, and a continuous curve indicating its temperature is automatically recorded. As the bolometer strip falls into each successive one of the lines of the spectrum, a nick comes in the curve.

Three approximately 60° flint-glass prisms in tandem were used to disperse the solar rays, and long-focus mirrors to collimate and focus the spectrum. Five photographic plates, each 60 centimeters long, were required to cover the spectrum from "A" in the red to "Ω" in the infra-red. Mr. Freeman did most of the final observing, and also measured the plates. Over 1,200 lines and bands of absorption were discovered, where only about 550 had been found in the earlier investigation published in 1900. A paper on this new work has been published as volume 82, No. 1, of the Smithsonian Miscellaneous Collections.

The other research carried through was the observation of the distribution of energy in the spectra of 18 stars and of the planets Mars and Jupiter. This was accomplished by Doctor Abbot with the aid of Doctor Adams, of Mount Wilson Observatory, employing the 100-inch telescope and a sensitive radiometer.

Greatly increased sensitiveness had been hoped for by substituting hydrogen for air, and an excessively light and small radiometer

system, built up with house flies' wings, for the somewhat larger mica-vane instrument employed by Doctor Abbot in 1923. With these improvements it was hoped that stars of the fourth or even fifth magnitude would be observable. These hopes were not altogether realized. The sensitiveness was potentially attained, but, unfortunately, could not be made available during the time of the experiments because a persistent slight charge of electricity which could not be removed created a governing field, which reduced the time of single swing of the system from about 10 seconds to only 1.5 seconds during the experiments. On this account the deflections in the stellar spectra were regrettably small. Nevertheless, with the special observing scale which had been devised, very satisfactory results were reached, and in one case on a star of only 3.8 magnitude. These observations have been published in the Astrophysical Journal for May, 1929.

(*b*) *Montezuma station.*—During the autumn of 1928 the apparatus at Montezuma seemed to grow insensitive, so that a critical inspection appeared necessary. By the generous financial assistance of Mr. John A. Roebling, it was possible to send Mr. Aldrich to Chile. This expedition occupied him from January to March, 1929. He rebuilt the galvanometer and repaired and adjusted other instruments until everything was in satisfactory condition. Excellent results have been coming in regularly of the Montezuma observations on the solar constant of radiation. These are published daily by the United States Weather Bureau.

(*c*) *Table Mountain station.*—The unfortunate trouble with the pyranometer at Table Mountain has already been described. Notwithstanding this, the results as now reduced seem satisfactory and are very numerous. Indeed, on several occasions Table Mountain has furnished consecutive daily runs of solar-constant determinations exceeding 50 days and once exceeding 70 days.

The Dobson ozone apparatus, owned by the Smithsonian and formerly in use at Montezuma, was returned to England for readjustment by Doctor Dobson. It was reinstalled at Table Mountain in the autumn of 1928 and daily determinations of atmospheric ozone have been made with it whenever possible since then. These measurements show in contrast with those formerly made at Montezuma about as much ozone in the higher atmosphere above California as has been found in Europe. Also, in contrast with Montezuma and in harmony with Europe, they show a decidedly variable quantity of ozone from day to day and from month to month. These ozone determinations will be continued at Table Mountain indefinitely.

(*d*) *Mount Brukkaros.*—The National Geographic station on Mount Brukkaros, South West Africa, which cooperates with Montezuma and Table Mountain in the daily observation of the solar

constant of radiation, has continued regular observations and has sent to Washington a large collection of records. These will be statistically and critically studied and prepared for publication.

As the observers, Messrs. Hoover and Greeley, have been three years in this African field, arrangements have been made for Messrs. Sordahl and Froiland to relieve them in August, 1929.

PERSONNEL

At the stations Mr. A. F. Moore has continued in charge at Table Mountain and Mr. H. H. Zodtner at Montezuma. Mr. Moore was assisted mainly by Mr. L. O. Sordahl, and after his departure, in June, 1929, by Dr. W. Weniger. Mr. Zodtner was assisted until April 1 by Mr. M. K. Baughman and after his resignation by Mr. C. P. Butler.

At Washington the force has remained unchanged, with three exceptions. Mrs. A. M. Bond resigned as computor on February 5, 1929. She was succeeded on February 18 by Miss M. Denoyer. Mr. H. B. Freeman, formerly in charge of Montezuma station, assisted at Mount Wilson and at Washington until May 1, 1929, when he obtained a transfer to the laboratories of the National Advisory Committee for Aeronautics at Langley Field, Va.

SUMMARY

The year has been notable for the satisfactory continuation at field stations of observations for the study of the variability of the sun; for the satisfactory completion of the critical statistical investigation of the results obtained at Table Mountain, so that hereafter Table Mountain observations may be definitively reduced by field observers; for the excellent accord found between definitive results of Table Mountain and Montezuma (stations 4,000 miles apart in opposite hemispheres) in their indications of solar variability; for the apparent confirmation of three definite periodicities of approximately 11, 15, and 26 months in solar variation; for the discovery of a new method of measuring the atmospheric ozone and its influence on solar-constant observations; for the repetition of a former investigation of solar and terrestrial absorption lines and bands in the solar spectrum, but with nearly threefold richer results; and for the observation of the distribution of energy in the spectra of 18 stars and two planets.

Respectfully submitted.

C. G. Abbot,
Director, Astrophysical Observatory.

The Secretary,
Smithsonian Institution.

APPENDIX 8

REPORT ON THE DIVISION OF RADIATION AND ORGANISMS

SIR: I have the honor to report the initial development of the new Division of Radiation and Organisms entered upon May 1, 1929.

The purpose of this division is to undertake those investigations of, or directly related to, living organisms wherein radiation enters as an important factor. Through the development of a thoroughly equipped physical and chemical laboratory wherein the spectroscopic side is most emphasized, investigations of biological problems can be undertaken more effectively than has generally been possible. Through the cooperation of men of diverse training in the fundamental, as well as the immediate biological sciences, it is hoped to secure the fullest advantage of modern specialization, which generally, on the contrary, presents a formidable handicap to work in border line fields.

The program of investigations falls into two main divisions:

I. Direct investigation upon living organisms.
II. Fundamental investigations related to biological problems.
 1. Molecular structure investigations.
 2. Photochemical investigations.

Direct investigations upon living organisms will, for the present, be concerned with the growth of plants under rigidly controlled physical and chemical conditions. Soil will be replaced by nutrient solutions of known constitution. The gases supplied to the plants will be of known and controlled amounts. Not only the temperature and humidity but the intensity and color of the light is to be measured and varied during the experiments.

Understanding of biological problems is greatly hampered by the lack of knowledge of the structure of the more complicated molecules which are a part of living organisms, and by a lack of knowledge of even the simpler chemical reactions brought about, or contributed to, by radiant energy. The most promising possibility for adding to our knowledge of molecular structure is offered by spectroscopic investigations; that is, through the study of the radiation arising from the internal vibrations of the molecules themselves. The study of photochemical phenomena requires both spectroscopic and chemical equipment.

All these investigations in common require a spectroscopic laboratory supported by both physical and chemical departments.

LABORATORIES

Space in the basement of the west wing of the Smithsonian Building, previously used for storage, is being renovated and equipped for laboratory purposes. Because of the very heavy walls, and the fact that the rooms are partially under ground, this space is peculiarly suited to the purpose, owing to its evenness of temperature. A large room on the north side will accommodate the plant-growth chambers, spectrographs, and photometer rooms. Adjoining, a small room will serve as dark room and enlarging room. Two smaller rooms on the south side of the wing complete the assignment of space. One of these is to be a physical laboratory accommodating infra-red recording spectroscopes and general manipulative equipment. The other of the smaller rooms has been subdivided, the larger portion to serve as a chemical laboratory and the smaller as a glass-blowing room.

The renovation of these rooms, subdivision, extension of plumbing, and construction of the very heavy electrical arteries required for the artificial illumination of the plants has been ably carried out by the National Museum personnel.

EQUIPMENT

The purchase of general equipment is nearing completion. Plans have been drawn up for a preconditioning chamber and construction has been begun. Drawings have been made for the actual growth chambers and bids are under consideration. Special apparatus for the construction of radiation-detecting devices is being made. Gratings for spectroscopic investigations are being purchased from the Johns Hopkins University. Much of the equipment formerly used in the infra-red investigation of Langley, Abbot, and Fowle will be used for the molecular-structure investigations through the courtesy of the Astrophysical Observatory.

FINANCIAL

The major portion of the expense for the coming year, approximating $20,000, will be cared for by means of grants from the Research Corporation. Of this sum approximately $12,000 will be spent upon salaries and the remaining $8,000 upon equipment. As the work develops it is hoped that it will so commend itself that larger means may become available.

ORGANIZATION

Personnel.—The present personnel is as follows:

Research associate, Dr. F. S. Brackett.
Consulting plant physiologist, Dr. E. S. Johnston.
Research assistant, L. B. Clark.
Stenographer and laboratory assistant, Miss V. P. Stanley.

Dr. F. S. Brackett took charge of this work under Doctor Abbot's direction May 1, his experience being chiefly physical and, more particularly, spectroscopic. Through the cordial cooperation of the agricultural experiment station of the University of Maryland, Dr. E. S. Johnston is directing the biological aspects of the investigation. In all this work the technical aspects involved in the development of new equipment will play a very important part. For this work the services of Mr. L. B. Clark have been secured, whose varied experience peculiarly fits him for such an undertaking.

Cooperation.—During some months previous to the initiation of this work in the Smithsonian, Doctor Brackett directed the development of several lines of research in the Fixed Nitrogen Laboratory closely related to those to be undertaken in this division. This work is being carried on by that laboratory now, in very close cooperation with the Smithsonian.

Respectfully submitted.

F. S. Brackett,
Research Associate in Charge.

Dr. C. G. Abbot,
Secretary, Smithsonian Institution.

APPENDIX 9

REPORT ON THE INTERNATIONAL CATALOGUE OF SCIENTIFIC LITERATURE

SIR: I have the honor to submit herewith the following report on the operations of the United States Regional Bureau of the International Catalogue of Scientific Literature for the fiscal year ended June 30, 1929:

Continuing the policy of keeping the expenditures of the bureau at a minimum until actual publication is resumed, the work here has consisted mainly in keeping necessary records of current scientific publications, preparing data for a revised list of journals, and other necessary routine matters, so that the actual work of indexing may be taken up by a full force as soon as reorganization of the enterprise is possible.

The gross expenditure for the year was $5,060.75 out of the appropriation of $7,460.

At the international convention of the International Catalogue of Scientific Literature held in Brussels July 22–24, 1922, the delegates officially representing the countries taking part in the enterprise anticipated that financial conditions would allow resumption of publication of the catalogue as soon as the financial chaos then existing should become stabilized. Looking forward to this event, they resolved to keep the organization alive by agreeing to continue the work of their regional bureaus so far as possible until financial support could be obtained. In Europe money to promote such scientific enterprises is still unobtainable; therefore, it appears that if this great bibliographical service is to be resumed aid must be extended from the United States, and that the time has come for this country to take the lead, not only in outlining a definite scheme for reorganization but in suggesting a possible means of obtaining necessary financial support. As a preliminary step this bureau has been in communication with Prof. Henry E. Armstrong, F. R. S., chairman of the executive committee, in whom the Brussels convention vested authority to consider and propose plans for resuming publication. In a letter on July 6, 1929, the writer stated:

I know, of course, how hard pressed all foreign countries have been financially, but the sums involved are so small and the results aimed at so valuable

and so greatly needed that I can not but believe that if some definite and concerted move is made now we can reorganize and renew this great work.

In his reply Professor Armstrong reflects the financial despondency of Europe but goes on to say:

> I wish it were possible to restart the International Catalogue, but I am bound to confess that I see no immediate prospect of doing so. Still, I would prophesy that it must again come into being—the idea was too grand and the proof obtained that the enterprise was entirely feasible too complete for it to remain an act unaccomplished. If the nations are ever to unite it must be in the field of natural science before anything else.

An outline of the present situation is briefly this: Publication of the International Catalogue of Scientific Literature began in 1901, when 33 of the leading countries of the world cooperated by establishing regional bureaus and furnishing to the central bureau in London classified index references to the scientific literature of their respective regions and further agreed to subscribe to a sufficient number of sets of the catalogue to support the central bureau and pay the cost of printing. Beginning with the literature of 1901, 17 volumes were published annually until the last volume of the fourteenth annual issue, indexing the literature of 1914, was published in 1922, making a total of 238 volumes, together with several extra volumes containing lists of journals and classification schedules.

The regional bureaus were supported locally, in most cases, by direct governmental grants, while the central bureau derived its sole support from the income received from subscribers to the catalogue, the price of which was equivalent to $85 per year for the complete set of 17 volumes. Just prior to the war central bureau receipts and expenditures approximately balanced, but after war began printing costs doubled, and it was therefore necessary to suspend publication in 1922.

The Royal Society of London acted as financial sponsor of the enterprise from the beginning, aided on several occasions by donations from other sources after war began.

The need of the International Catalogue of Scientific Literature is obvious, as no publication ever existed so broad in scope or exhaustive in treatment and none has since taken its place.

The various abstract journals do not meet the need of libraries as reference aids, as they overlap their respective fields and in aggregate are too bulky, expensive, and dissimilar in plan to serve as general works of reference. Abstract journals serve the immediate need of specialists but do not meet the requirements of librarians or general students.

Before outlining a scheme for reorganization and improvement for the future, a retrospect of the work may be considered and defects noted in order that they may be eliminated in the future.

The organization was started on very limited and borrowed capital, which greatly added to the cost of production, as it was necessary to have all printing done by private firms. The cost of subscription, $85 per year, placed the work beyond the means of many small libraries and individual workers. It was originally intended to make the several volumes yearbooks of their respective fields, and much of the value and use of the work was lost owing to the fact that many of the volumes were delayed in their publication. This vital defect may be remedied by having editing and publishing done by the same organization. To accomplish this, it will be necessary to own a printing plant designed and equipped solely for this purpose. This will make possible continuous and prompt printing at a minimum cost and so reduce the cost that it will be possible to offer the catalogue to subscribers for $50 per set instead of $85, if an edition of 1,000 sets can be sold.

Estimates of the cost of equipping and operating a suitable printing plant have been made by several printers and publishers in this country and by the two leading manufacturers of typesetting machines. These estimates were almost identical, and from them it appears that a suitably equipped plant can be installed for less than $30,000, in which, when properly manned, a catalogue aggregating 10,000 pages a year can be published for $17,500 in an edition of 1,000. This sum includes cost of labor, paper, repairs, and incidentals. To this sum must be added $15,000 for the annual expenses of the central bureau for one year with which to pay rent and the executive and editorial staffs and, say $12,500 as a liberal reserve to meet incidental and unforeseen expenses which always occur in beginning any new enterprise. It thus appears that the money needed is—

For installing and equipping the printing plant		$30,000
Expenses for printing and publishing for one year	$17,500	
Maintenance of central bureau for one year	15,000	
Allowance for unforeseen incidentals	12,500	
		45,000
Total capital needed for first year		75,000

After the first year, to continue the work would cost approximately $35,000 per year, leaving a margin of $15,000 per year between the cost of production and the estimated receipts if the total edition of 1,000 copies can be sold. This amount, together with sums derived from the first year sales already included in the estimates, could be made a sinking fund with which to repay donors.

Should publication be resumed it is expected that a demand for the first 14 annual issues will arise, and as there is a large supply of them now at the central bureau, money received from this source

may be used to repay the Royal Society of London for the sums advanced for their publication.

The necessary steps to be taken leading to reorganization and resumption of publication appear to be the following:

(1) Preparation by the existing executive committee of a definite course and detailed plan of reorganization and operation.

(2) Obtaining promises of cooperation from the various regional bureaus to again furnish the necessary data for the catalogue.

(3) Canvassing possible fields for subscriptions and the necessary financial aid.

Obviously, capital is essential before any actual work can be begun, but definite plans may be prepared by those now vested with authority to act, and when this part of the work has progressed sufficiently to be able to submit a definite and concise prospectus to subscribers and possible donors it is proposed to solicit support from both.

Respectfully submitted.

LEONARD C. GUNNELL,
Assistant in Charge.

Dr. CHARLES G. ABBOT,
Secretary, Smithsonian Institution.

APPENDIX 10

REPORT ON THE LIBRARY

SIR: I have the honor to submit the following report on the activities of the library of the Smithsonian Institution for the fiscal year ended June 30, 1929:

THE LIBRARY

The Smithsonian library, or, speaking in terms that accord more exactly with the recent reorganization of the library, the Smithsonian library system, is made up of 10 divisional and 36 sectional libraries. The former consist of the Smithsonian deposit in the Library of Congress, which is the main library of the Institution; the library of the United States National Museum; the Smithsonian office library; the Langley aeronautical library; the radiation and organisms library; and the libraries of the Astrophysical Observatory, the Bureau of American Ethnology, the National Gallery of Art, the Freer Gallery of Art, and the National Zoological Park. The sectional libraries are the immediate working tools of the curators in the National Museum. These 46 libraries taken together, including the collections not yet catalogued, comprise about 800,000 volumes, pamphlets, and charts. Although they contain thousands of publications on history, philosophy, literature, and the fine arts, they are largely scientific and technological in character, among them being many society and serial publications. Not only is this great collection an invaluable instrument in the work of the Institution and the Government, but it is freely available both to scholars and to the public generally for research purposes.

The composition of the Smithsonian library underwent several important changes during the past year. The library of the Bureau of American Ethnology became a division of the library; the library of radiation and organisms, designed for the use of a new branch of Smithsonian activity, was organized as a divisional library; and the technological library was made a part of the library of the National Museum.

THE STAFF

Early in the year the second position of assistant librarian—that of chief of the accessions department—was established and was filled

may be used to repay the Royal Society of London for the sums advanced for their publication.

The necessary steps to be taken leading to reorganization and resumption of publication appear to be the following:

(1) Preparation by the existing executive committee of a definite course and detailed plan of reorganization and operation.
(2) Obtaining promises of cooperation from the various regional bureaus to again furnish the necessary data for the catalogue.
(3) Canvassing possible fields for subscriptions and the necessary financial aid.

Obviously, capital is essential before any actual work can be begun, but definite plans may be prepared by those now vested with authority to act, and when this part of the work has progressed sufficiently to be able to submit a definite and concise prospectus to subscribers and possible donors it is proposed to solicit support from both.

Respectfully submitted.

LEONARD C. GUNNELL,
Assistant in Charge.

DR. CHARLES G. ABBOT,
Secretary, Smithsonian Institution.

APPENDIX 10

REPORT ON THE LIBRARY

SIR: I have the honor to submit the following report on the activities of the library of the Smithsonian Institution for the fiscal year ended June 30, 1929:

THE LIBRARY

The Smithsonian library, or, speaking in terms that accord more exactly with the recent reorganization of the library, the Smithsonian library system, is made up of 10 divisional and 36 sectional libraries. The former consist of the Smithsonian deposit in the Library of Congress, which is the main library of the Institution; the library of the United States National Museum; the Smithsonian office library; the Langley aeronautical library; the radiation and organisms library; and the libraries of the Astrophysical Observatory, the Bureau of American Ethnology, the National Gallery of Art, the Freer Gallery of Art, and the National Zoological Park. The sectional libraries are the immediate working tools of the curators in the National Museum. These 46 libraries taken together, including the collections not yet catalogued, comprise about 800,000 volumes, pamphlets, and charts. Although they contain thousands of publications on history, philosophy, literature, and the fine arts, they are largely scientific and technological in character, among them being many society and serial publications. Not only is this great collection an invaluable instrument in the work of the Institution and the Government, but it is freely available both to scholars and to the public generally for research purposes.

The composition of the Smithsonian library underwent several important changes during the past year. The library of the Bureau of American Ethnology became a division of the library; the library of radiation and organisms, designed for the use of a new branch of Smithsonian activity, was organized as a divisional library; and the technological library was made a part of the library of the National Museum.

THE STAFF

Early in the year the second position of assistant librarian—that of chief of the accessions department—was established and was filled

by the appointment of Miss Ethel A. L. Lacy, a graduate of the University of Michigan, who had had many years of experience in the library of the Department of Agriculture and the Detroit Public Library.

Mrs. Hope Hanna Simmons was given a permanent position as junior library assistant and was placed in charge of the reading and reference room in the Arts and Industries Building.

Miss Agnes Auth, minor library assistant, after 10 years of faithful service in the library, was appointed to a higher position in the disbursing office of the Institution.

Mr. Herschel Chappell, assistant messenger, was advanced to a position in the office of the chief clerk. He was succeeded by Mr. William Oliver Grant.

Several members of the staff were granted brief periods of leave for travel and study. Miss Elisabeth Hobbs spent some weeks in England, and Miss Mary D. Ashton in Oregon, while Miss Ruth Wenger attended advanced courses in library science at the University of California.

In the course of the year the following persons were employed temporarily: Miss Helen V. Barnes, Mr. Alan Blanchard, Mr. Dale Hawarth, Mr. Thomas Hickok, Mr. John Paschall, Mrs. M. Landon Reed, Miss Jeannette Seiler, Mrs. Hope H. Simmons, and Mr. Clyde Williams.

EXCHANGE OF PUBLICATIONS

Nearly all of the publications currently received by the various libraries in the Smithsonian system are sent by editors of journals and by learned institutions and societies throughout the world in exchange for the publications of the Institution and its branches. This exchange has been, from the early days of the Institution, the chief means of increasing its library, and has brought to it a wealth of scientific material. This has come partly by mail, but mainly through the International Exchange Service, which is administered by the Institution.

During the last fiscal year the Smithsonian library received 30,502 packages, of one or more publications each. After the packages had been opened the items were entered, stamped, and sent to the proper divisions and sections of the library, but chiefly to the Smithsonian deposit in the Library of Congress and the library of the United States National Museum. Most of the 1,316 letters and the thousands of acknowledgments written by the library during the year had to do with this exchange of publications. Exchange relations were taken up with many new societies and with many old societies for new publications.

Among the items received were dissertations from the universities of Berlin, Bern, Breslau, Bonn, Cornell, Erlangen, Freiberg, Giessen, Halle, Helsingfors, Johns Hopkins, Kiel, Leipzig, Louvain, Neuchâtel, Pennsylvania, Rostock, Strasbourg, Tubingen, Utrecht, Wurzburg, and Zürich; and from technical schools at Berlin, Bonn, Braunschweig, Darmstadt, Dresden, Freiberg, Karlsruhe, and Zürich.

GIFTS

The outstanding gift of the year was that of the Harriman Alaskan library. This is the collection relating to Alaska and the Arctic regions made by Dr. William H. Dall, late curator in the National Museum, who for nearly a lifetime was a student of the regions of the north. It consists of approximately 1,100 volumes and pamphlets, together with 30 or more scrapbooks of letters and newspaper clippings. It is rich in works on exploration and discovery, and contains many rare items, including a file of the Alaska Herald from 1868 to 1875. The library was purchased and presented to the Institution by Mrs. Edward H. Harriman, whose husband, it will be remembered, made possible by his generosity the famous Harriman expedition to Alaska in 1899, in which Doctor Dall and other scientists from the Smithsonian Institution and the Washington Academy of Sciences took a leading part, and the results of which the Institution published later in a monumental work. The library will be made available for reference at the earliest possible moment.

Also prominent among the gifts were these: 1,000 publications and manuscripts of a miscellaneous character, from Mr. Herbert A. Gill, of Washington, D. C., brother of the late Dr. Theodore Gill, at one time librarian and associate in zoology at the Smithsonian Institution; 500 books and periodicals on photography, from Mr. A. B. Stebbins, of Canisteo, N. Y.; two sets of the first four volumes of the Smithsonian Scientific Series, Patrons' Edition, from the Smithsonian Institution; several hundred scientific publications, many in continuation of series already given, from the American Association for the Advancement of Science, the Hygienic Laboratory, and the Geophysical Laboratory; and about 1,500 publications of the Philosophical Society of Washington, from the society itself, to be used for completing sets in the library, for exchange, or for free distribution.

Many other gifts were received, including copies of the following: The phototype edition of Codex Argenteus Upsaliensis, recently issued by the Royal University of Upsala in order to celebrate its four hundred and fiftieth anniversary, from the University; Innermost Asia—a detailed report, in four volumes, of explorations in Central Asia, Kan-su, and Eastern Iran, carried out and described under the orders of H. M. Indian Government by Sir Aurel Stein,

of the Indian Archaeological Survey—presented by the secretary to the High Commissioner for India; North American Wild Flowers, volume 4, by Mary Vaux Walcott, from the artist-author; A Link with Magellan, being a chart of the East Indies, C. 1522, in the possession of Boies Penrose, from Mr. Penrose; Enthronement of the One Hundred Twenty-fourth Emperor of Japan, from the Japan Advertiser, Tokyo; and Metropolitan Museum Color-prints, series 1–8, with several other publications, from the Metropolitan Museum of Art.

Among donors on the staff of the Institution and its branches were Dr. Charles G. Abbot, secretary of the Smithsonian, and Dr. William H. Holmes, director of the National Gallery of Art, who, as in previous years, were generous contributors of publications of different kinds; Dr. Charles W. Richmond, who gave many volumes, some quite rare, chiefly on ornithology; and Miss Mary J. Rathbun, whose gifts during the year increased her total gifts to the library to more than 200 pieces, exclusive of her own publications. Still other gifts came from Assistant Secretary Wetmore, Mr. W. de C. Ravenel, Dr. R. S. Bassler, Dr. F. W. Clarke, Mr. Paul Garber, Dr. J. W. Gidley, Mr. A. J. Olmsted, Mr. J. H. Riley, Miss Louise A. Rosenbusch, Dr. Waldo L. Schmitt, and Mr. Ralph Smith.

OFFICE LIBRARY

The office library, which is made up of the publications of the Institution and its branches, various sets of society publications, the art-room collection, the employees' library, and many works of reference, some of which are in the reference room in the Smithsonian Building and the rest in other parts of the library or in the administrative offices of the Institution, is one of the most used of the libraries in the Smithsonian system. Especially is this true of the employees' collection, which is now shelved in the reading room of the Arts and Industries Building. The usefulness of this collection was greatly increased during the last year by generous loans of current works of general literature from the Library of Congress. These loans were so much appreciated by the Smithsonian staff that it is hoped they will become a permanent feature in the cooperation of the two institutions. To the office library were added 144 volumes and 16 pamphlets. The binding of volumes for the library, which had been discontinued for several years for lack of funds, was resumed and 41 volumes were bound.

SMITHSONIAN DEPOSIT

The Smithsonian deposit in the Library of Congress is the largest and most important unit in the Smithsonian library system, number-

ing about 500,000 volumes, pamphlets, and charts, besides many volumes awaiting completion. This collection, which began with the founding of the Institution in 1846, was housed in the Smithsonian Building until 1866. In that year it had grown to 40,000 volumes, and was, by permission of Congress, deposited in the Library of Congress. Since that time it has been steadily increased by additions from the Institution. While it is somewhat general in character, its interest is mainly scientific, and it is rich in serial publications and monographs, and especially in the reports, proceedings, and transactions of the learned societies and institutions of the world, being one of the foremost collections of its kind. Although, of course, distributed throughout the Library of Congress according to classification, the deposit is, because of its prevailingly scientific nature, chiefly in the Smithsonian division, which was established in 1900 to take care of the scientific publications both of the deposit and of the Library of Congress.

During the last fiscal year the Institution sent to the deposit 19,003 publications, comprising 3,569 volumes, 9,506 parts of volumes, 5,616 pamphlets, and 312 charts. Documents of foreign governments, largely statistical in character, to the number of about 4,000, were also forwarded, without being stamped or entered, to the document division of the Library of Congress. Among the items sent to the deposit were 1,110 volumes in Japanese on education, several hundred in Russian on various subjects, and 56 in Turkish. The last had been presented to the Institution many years before by H. I. M. the Sultan Abdul-Hamid II. Among them, too, were 4,729 dissertations from 30 universities and technical schools at home and abroad. The publications also included a large number intended for use in building up reserve sets. Some of these were taken from the duplicates in the Smithsonian Building, which have lately been made available; others from the publications recently given to the Institution by the American Association for the Advancement of Science. It is particularly pleasing to report that, as the result of the reorganization of the accessions department of the library, nearly twice as many volumes and parts were obtained in response to requests from the deposit as were obtained the year before.

NATIONAL MUSEUM LIBRARY

The library of the United States National Museum, which consists, in the main, of works on natural history and mechanical and mineral technology, is housed partly in the Natural History Building and partly in the Arts and Industries Building. In addition to the two main collections it includes 36 smaller collections, which are the sectional libraries of the curators. The library contains 74,562 vol-

umes and 107,629 pamphlets. It was increased during the past year by 2,247 volumes and 748 pamphlets. Some of the additions came by purchase and gift, but most by exchange.

The current work was kept up as usual, but often by a depleted force. The staff entered 9,759 parts of periodicals, catalogued 1,422 volumes and pamphlets, and had 1,331 volumes bound. They sent to the sectional libraries 5,518 publications and loaned to the curators and their assistants 4,793, of which 2,163 were borrowed from the Library of Congress and 271 elsewhere. They returned 2,336 books to the Library of Congress and 299 to other libraries. About 200 publications were loaned to Government libraries and to libraries outside of Washington. Among the latter were those of the American Museum of Natural History, Carnegie Museum, Field Museum, Department of Agriculture of Canada, E. I. du Pont de Nemours & Co. Experimental Station, and the following colleges and universities: Buffalo, California, Goucher, Minnesota, and Princeton. One loan to the Field Museum consisted of a duplicate set, in 43 volumes, of Linnaea, Berlin, 1825–1882, and was made on semipermanent charge. It was the third loan of the kind during the last three years, the others having been made to Johns Hopkins University and the University of Chicago. All three were for the furthering of specialized scientific research, in keeping with the general purpose of the Museum, as a branch of the Smithsonian Institution, of increasing and diffusing knowledge.

About as many publications as usual were consulted in the library. But there was a marked growth in the reference and informational service rendered by the staff, not only to the scientists of the Institution and to investigators from different departments of the Government, but to scholars generally and to inquirers throughout the country. In this connection special attention should be called to the growing importance, both to the employees of the Smithsonian Institution and its branches and to the visiting public, of the recently reorganized reading and reference room, with its loan and information desk, in the Arts and Industries Building. In the course of the year the assistant in charge, besides performing her other duties, recorded 700 visitors, answered more than 200 inquiries for information, some involving a good deal of research, and loaned nearly 3,000 books and periodicals.

Because of the amount and urgency of the current work and the smallness of the staff, only a little time was found during the year for the further revision of the catalogue, the completing of the shelf list, or the solving of the major problems that are calling for attention in the sectional libraries. Time was found, however, for supplying many of the publications needed by these libraries, pre-

paring their volumes for binding, and doing several other pieces of work for them, notably in the sections of botany, geology, and mammals. These libraries number 36, and are as follows:

Administration.
Administrative assistant's office.
American archeology.
Anthropology.
Biology.
Birds.
Botany.
Echinoderms.
Editor's office.
Ethnology.
Fishes.
Foods.
Geology.
Graphic arts.
History.
Insects.
Invertebrate paleontology.
Mammals.
Marine invertebrates.
Mechanical technology.
Medicine.
Minerals.
Mineral technology.
Mollusks.
Old World archeology.
Organic chemistry.
Paleobotany.
Photography.
Physical anthropology.
Property clerk's office.
Reptiles and batrachians.
Superintendent's office.
Taxidermy.
Textiles.
Vertebrate paleontology.
Wood technology.

BUREAU OF AMERICAN ETHNOLOGY LIBRARY

During the year the library of the Bureau of American Ethnology became a division of the Smithsonian library. This collection consists almost exclusively of works on anthropology, particularly those pertaining to the American aborigines, covering especially the linguistics, history, archeology, myths, religion, arts, sociology, and general culture of the American Indian. The library also has files of manuscript material, photographs, and Indian vocabularies. It was increased during the last year by 591 volumes and 200 pamphlets, and now contains 28,512 volumes and 16,377 pamphlets. The staff prepared 418 volumes for binding, and made considerable progress toward providing Library of Congress cards for the catalogue.

ASTROPHYSICAL OBSERVATORY LIBRARY

The library of the Astrophysical Observatory, which is kept partly in the observatory and partly in the main hall of the Smithsonian Building, is an important instrument in the astrophysical and meteorological work of the Institution, being of particular value just now in connection with its researches in solar radiation. It consists of 3,868 volumes and 2,949 pamphlets, of which 101 volumes and 224 pamphlets were added during the last year. The number of volumes bound was 64.

RADIATION AND ORGANISMS LIBRARY

Late in the year a new division of the Smithsonian library was established to meet the needs of the Institution's work in radiation and organisms. A list of the significant books and periodicals in the field was prepared, in cooperation with the chief of the bureau, and effort will be made immediately to obtain, by exchange or purchase, those that can not be borrowed from other units of the library.

LANGLEY AERONAUTICAL LIBRARY

The Langley aeronautical library, while consisting of only 1,697 volumes and 838 pamphlets, is one of the most prominent divisions of the Smithsonian library, as it contains many rare items, including complete files of the early aeronautical magazines. Some of these were in the original collection as it came from Samuel Pierpont Langley, the third secretary of the Institution, in whose memory the library was named. Others were among the publications given since by Alexander Graham Bell, Octave Chanute, and James Means. The library also has a large number of photographs, letters, and newspaper clippings. It is consulted continually by experts from the departments of the Government, from the embassies in Washington, and from aeronautical and other organizations in different parts of the country. The library was increased during the past year by 85 volumes and 138 pamphlets. The new catalogue, which had been begun the year before, was finished and the collection labeled and rearranged.

NATIONAL GALLERY OF ART LIBRARY

The library of the National Gallery of Art, which for the present is housed, with the gallery, in the Natural History Building, comprises 1,001 volumes and 1,106 pamphlets, chiefly on the art of the United States and Europe. The collection has been chosen with great care and has been slowly increased as funds and space permitted, with a view to becoming the nucleus of a much larger and more representative working library when the special building now in prospect for the gallery is provided. During the last year 153 volumes and 82 pamphlets were added to the collection and 33 volumes were bound. Most of the accessions came, as usual, by purchase and exchange, but many came by gift, notably from Dr. William H. Holmes, director of the gallery.

FREER GALLERY OF ART LIBRARY

The library of the Freer Gallery of Art concerns itself almost entirely with the interests represented by the collections of art objects pertaining to the arts and cultures of the Far East, India,

Persia, and the nearer East; by the life and works of James McNeill Whistler and of certain other American painters whose pictures are owned by the gallery; and, further, to a limited extent, by the Biblical manuscripts of the fourth and fifth centuries, which, as the possession of the Freer Gallery, are known as the Washington Manuscripts. It contains many works in the Chinese and Japanese languages, some of which are very rare, and thus supplements for research purposes the oriental division of the Library of Congress. During the year just closed the library was increased by 345 volumes and 191 pamphlets. Of these, 114 volumes were added to the collection designed for the use of the field staff of the gallery. This collection now numbers about 814 volumes and 500 pamphlets, while the main library totals 4,269 volumes and 2,769 pamphlets. Two of the noteworthy accessions were Sir Aurel Stein's Innermost Asia and a copy of the Codex Argenteus Upsaliensis, the latter of which was received as a gift by the Smithsonian Institution from the University of Upsala and assigned to the library of the gallery as a fitting addition to the Biblical material already on its shelves. Among the visitors there was the usual large number of readers and students, some of whom came to study the facsimiles of the Washington Manuscripts, and others to make drawings or tracings from material in the library. The number of volumes bound was 82.

NATIONAL ZOOLOGICAL PARK LIBRARY

The library of the National Zoological Park, which is kept in the administration building at the park, is the immediate working collection of the director and his assistants. It consists of about 1,209 volumes and 400 pamphlets, chiefly on animals and the care of them. The number of accessions for the year was 9 volumes and 100 pamphlets, and of volumes bound, 5.

SUMMARY OF ACCESSIONS

The accessions for the year may be summarized as follows:

Library	Volumes	Pamphlets and charts	Total
Astrophysical Observatory	101	224	325
Bureau of American Ethnology	591	200	791
Freer Gallery of Art	345	191	536
Langley aeronautical	85	138	223
National Gallery of Art	153	82	235
National Zoological Park	9	100	109
Radiation and organisms			
Smithsonian deposit, Library of Congress	3,569	5,928	9,497
Smithsonian office	144	16	160
United States National Museum	2,247	748	2,995
Total	7,244	7,627	14,871

The estimated number of volumes, pamphlets, and charts in the Smithsonian library on June 30, 1929, was as follows:

Volumes	563, 106
Pamphlets	180, 475
Charts	24, 972
Total	768, 553

This number does not include the many thousands of volumes in the library still uncatalogued or awaiting completion.

THE UNION CATALOGUE

Considerable progress was made during the year on the union catalogue of the libraries in the Smithsonian system, and that, too, despite the fact that the catalogue department was very much undermanned. In addition to doing the current work in the different libraries, the staff finished cataloguing the Langley aeronautical collection. It will next take up the John Donnell Smith and Watts de Peyster collections. It will also make a special effort to complete the shelf list in the library of the National Museum. The following statistics show the work of the year in detail:

Volumes catalogued	2, 199
Volumes recatalogued	907
Pamphlets catalogued	2, 080
Pamphlets recatalogued	3, 676
Charts catalogued	316
Charts recatalogued	2
Typed cards added to catalogue	8, 490
Library of Congress cards added to catalogue	22, 961

PHYSICAL CONDITION AND EQUIPMENT

Mention was made in the librarian's last report of the improved physical condition and equipment of the reading room in the Arts and Industries Building. Since that report appeared there has been a similar improvement in two other units of the library. In the Natural History Building the three rooms used for library purposes were painted, new lights and ventilators were installed, a cork runner was laid the full length of the reference and stack rooms, and the two large awkward reading tables were converted into four attractive small ones. In the Smithsonian Building the five library rooms were painted and new shades provided for the windows, and several ranges of steel shelving were purchased for the catalogue room.

SPECIAL ACTIVITIES

Among the special activities of the year several should be mentioned.

Further progress was made in organizing the scientific material in the west stacks of the main building, so that by the close of the year most of it was in order. The finishing of this long, difficult task will greatly facilitate the exchange work of the library. Already many hundreds of publications have been found that were needed by sets in the various libraries of the Institution.

As a result of the work in the west stacks about 1,900 publications of a miscellaneous character, many in Japanese and Russian, were sent to the Smithsonian deposit and the document division of the Library of Congress.

The work of selecting from the Smithsonian duplicates items to be used in exchange with other libraries for material needed by the Institution was considerably advanced. In this connection 2,400 publications were sent to Harvard University and 2,900 to Yale. Other sendings will soon be made to Chicago University, Catholic University, and the Marine Biological Laboratory at Woods Hole.

Nearly 1,800 publications of State geological surveys were assembled from various unorganized collections in the Smithsonian Building and the Arts and Industries Building and many of them used toward completing sets in the library. Those not needed will be offered to the library of the Geological Survey.

About 10,000 publications of State agricultural experiment stations, which had been received and shelved by the library for many years, but which had little to do with the work of the Institution or its branches, were given to the library of the Department of Agriculture.

A collection of 667 reprints was sorted according to subject and distributed to the curators concerned.

The cards of the Wistar Institute were filed to date, and the Concilium Bibliographicum cards pertaining to mammals were deposited in the section of mammals.

The popular and semipopular material that, pending final disposal, had been stored in the basement of the Smithsonian Building, was transferred to a special building on the grounds of the Astrophysical Observatory and arranged.

The work of reorganizing the east stacks of the main building was begun, to make room for the growth of the reference department of the Institution and of the library of the Bureau of American Ethnology.

Special attention was given by the accessions department to the want cards from the Smithsonian deposit and the library of the National Museum, with the result that the correspondence based upon them will be brought up to date within a few weeks.

CONCLUSION

Finally, it is gratifying to report that the special allotment of $500 for expenses, made the past year for the first time, enabled the library to purchase important books, periodicals, and equipment for the office library that it could not otherwise have obtained. During the year to come the amount that will be available for books and periodicals for the Museum will be increased by $500. This will be pleasant news to the curators, who have been waiting patiently for the time when it would be possible for the library to get more of the publications essential to their work that can not be secured by exchange.

Among the needs of the library the most urgent is that of funds to establish permanent positions for two more cataloguers, another library assistant, a correspondence clerk, a stenographer, a typist, and another messenger. It is hoped that at least several of these positions can be provided for by the close of the next fiscal year, in order that the unfinished tasks that the library has inherited from the past, its current work, which is increasing steadily, and its new projects, may be expedited.

Respectfully submitted.

William L. Corbin,
Librarian.

Dr. Charles G. Abbot,
Secretary, Smithsonian Institution.

APPENDIX 11

REPORT ON THE PUBLICATIONS

Sir: I have the honor to submit the following report on the publications of the Smithsonian Institution and the Government bureaus under its administrative charge during the year ending June 30, 1929:

The Institution proper published during the year 16 papers in the series of Smithsonian Miscellaneous Collections, 1 annual report, and pamphlet copies of the 27 articles contained in the report appendix, and 5 special publications. The Bureau of American Ethnology published 3 annual reports and 5 bulletins. The United States National Museum issued 1 annual report, 2 volumes of proceedings, 4 complete bulletins, 1 part of a bulletin, 2 parts in the series Contributions from the United States National Herbarium, and 59 separates from the proceedings.

Of these publications there were distributed during the year 197,573 copies, which included 64 volumes and separates of the Smithsonian Contributions to Knowledge, 31,121 volumes and separates of the Smithsonian Miscellaneous Collections, 26,709 volumes and separates of the Smithsonian annual reports, 3,773 Smithsonian special publications, 115,128 volumes and separates of the various series of the National Museum publications, 20,112 publications of the Bureau of American Ethnology, 177 publications of the National Gallery of Art, 47 volumes of the Annals of the Astrophysical Observatory, 16 reports of the Harriman Alaska expedition, and 352 reports of the American Historical Association.

SMITHSONIAN MISCELLANEOUS COLLECTIONS

Of the Smithsonian Miscellaneous Collections, volume 73, 2 papers were issued; volume 75, 1 paper and title-page, table of contents, and index; and of volume 81, 13 papers, as follows:

VOLUME 73

No. 5. Opinions Rendered by the International Commission on Zoological Nomenclature. Opinions 98 to 104. September 19, 1928. 28 pp. (Publ. 2973.)

No. 6. Opinions Rendered by the International Commission on Zoological Nomenclature. Opinions 105 to 114. June 8, 1929. 26 pp. ((Publ. 3016.)

VOLUME 75

No. 5. Cambrian Geology and Paleontology, V. No. 5. Pre-Devonian Paleozoic Formations of the Cordilleran Provinces of Canada. By Charles D. Walcott. September 14, 1928. Pp. 175–368, pls. 26–108, text figs. 24–35.

Title-page, table of contents and index. (Publ. 2976.)

VOLUME 81

No. 1. Mexican Mosses Collected by Brother Arsène Brouard—II. By I. Thériot. August 15, 1928. 26 pp., 9 text figs. (Publ. 2966.)

No. 2. Cambrian Fossils from the Mohave Desert. By Charles E. Resser. July 5, 1928. 10 pp., 3 pls. (Publ. 2970.)

No. 3. Morphology and Evolution of the Insect Head and Its Appendages. By R. E. Snodgrass. November 20, 1928. 158 pp., 57 text figs. (Publ. 2971.)

No. 4. Drawing by Jacques Lemoyne De Morgues of Saturioua, a Timucua Chief in Florida, 1564. By David I. Bushnell. August 23, 1928. 9 pp., 1 pl., 1 text fig. (Publ. 2972.)

No. 5. The Relations Between the Smithsonian Institution and the Wright Brothers. By Charles G. Abbot. September 29, 1928. 27 pp. (Publ. 2977.)

No. 6. A Study of Body Radiation. By L. B. Aldrich. December 1, 1928. 54 pp., 9 text figs. (Publ. 2980.)

No. 7. Recent Archeological Developments in the Vicinity of El Paso, Tex. By Frank H. H. Roberts, jr. January 25, 1929. 14 pp., 5 pls., 8 text figs. (Publ. 3009.)

No. 8. Parasites and the Aid They Give in Problems of Taxonomy, Geographical Distribution, and Paleogeography. By Maynard M. Metcalf. February 28, 1929. 36 pp. (Publ. 3010.)

No. 9. A Second Collection of Mammals from Caves Near St. Michel, Haiti. By Gerrit S. Miller, jr. March 30, 1929. 30 pp., 10 pls. (Publ. 3012.)

No. 10. Tropisms and Sense Organs of Lepidoptera. By N. E. McIndoo. April 4, 1929. 59 pp., 16 text figs. (Publ. 3013.)

No. 11. Atmospheric Ozone: Its Relation to Some Solar and Terrestrial Phenomena. By Frederick E. Fowle. March 18, 1929. 27 pp., 13 text figs. (Publ. 3014.)

No. 12. Archeological Investigations in the Taos Valley, N. Mex., during 1920. By J. A. Jeancon. June 11, 1929. 29 pp., 15 pls., 14 text figs. (Publ. 3015.)

No. 13. Descriptions of Four New Forms of Birds from Hispaniola. By Alexander Wetmore. May 15, 1929. 4 pp. (Publ. 3021.)

SMITHSONIAN ANNUAL REPORTS

Report for 1927.—The complete volume of the Annual Report of the Board of Regents for 1927 was received from the Public Printer in October, 1928.

Annual Report of the Board of Regents of the Smithsonian Institution showing operations, expenditures, and condition of the Institution for the year ending June 30, 1927. xii+580 pp., 99 pls., 44 text figs. (Publ. 2927.)

The appendix contained the following papers:

The Accomplishments of Modern Astronomy, by C. G Abbot.
Recent Developments of Cosmical Physics, by J. H. Jeans.
The Evolution of Twentieth-Century Physics, by Robert A. Millikan.
Isaac Newton, by Prof. Albert Einstein.

The Nucleus of the Atom, by J. A. Crowther

The Centenary of Augustin Fresnel, by E. M. Antoniadi.

Soaring Flight, by Wolfgang Klemperer.

The Coming of the New Coal Age, by Edwin E. Slosson.

Is the Earth Growing Old? By Josef Felix Pompeckj.

Geological Climates, by W. B Scott.

The Geologic Romance of the Finger Lakes, by Prof. Herman F. Fairchild.

Fossil Marine Faunas as Indicators of Climatic Conditions, by Edwin Kirk.

Paleontology and Human Relations, by Stuart Weller.

At the North Pole, by Lincoln Ellsworth.

Bird Banding in America, by Frederick C. Lincoln.

The Distribution of Fresh-water Fishes, by David Starr Jordan.

The Mind of an Insect, by R. E. Snodgrass.

The Evidence Bearing on Man's Evolution, by Aleš Hrdlička.

The Origins of the Chinese Civilization, by Henri Maspero.

Archeology in China, by Liang Chi-Chao.

Indian Villages of Southeast Alaska, by Herbert W. Krieger.

The Interpretation of Aboriginal Mounds by Means of Creek Indian Customs, by John R. Swanton.

Friederich Kurz, Artist-Explorer, by David I. Bushnell, jr.

Note on the Principles and Process of X-Ray Examination of Paintings, by Alan Burroughs.

The Lengthening of Human Life in Retrospect and Prospect, by Irving Fisher.

Charles Doolittle Walcott, by George Otis Smith.

William Healey Dall, by C. Hart Merriam.

Report for 1928.—The report of the executive committee and proceedings of the Board of Regents of the Institution and the report of the secretary, both forming parts of the annual report of the Board of Regents to Congress, were issued in December, 1928.

Report of the executive committee and proceedings of the Board of Regents of the Smithsonian Institution for the year ending June 30, 1928. 14 pp. (Publ. 2979.)

Report of the Secretary of the Smithsonian Institution for the year ending June 30, 1928. 147 pp. (Publ. 2978.)

The general appendix to this report, which was in press at the close of the year, contains the following papers:

The Wider Aspects of Cosmogony, by J. H. Jeans.

The Stars in Action, by Alfred H. Joy.

Island Galaxies, by A. Vibert Douglas.

Astronomical Telescopes, by F. G. Pease.

New Results on Cosmic Rays, by R. A. Millikan and G. H. Cameron.

Three Centuries of Natural Philosophy, by W. F. G. Swann.

The Hypothesis of Continental Displacement, by C. Schuchert.

On Continental Fragmentation and the Geologic Bearing of the Moon's Surficial Features, by Joseph Barrell.

The "Craters of the Moon" in Idaho, by H. T. Stearns.

The Oldest Known Petrified Forest, by W. Goldring.

Water Divining, by J. W. Gregory.

Some Problems of Polar Geography, by R. N. Rudmose Brown.

Birds of the Past in North America, by Alexander Wetmore.

Mammalogy and the Smithsonian Institution, by Gerrit S. Miller, jr.

The Controversy Over Human "Missing Links," by Gerrit S. Miller, jr.

What is known of the Migrations of Some of the Whalebone Whales, by Remington Kellogg.

Ecology of the Red Squirrel, by A. Brooker Klugh.

Adventures of a Naturalist in the Ceylon Jungle, by Casey A. Wood.

Communication Among Insects, by N. E. McIndoo.

Our Insect Instrumentalists and Their Musical Technique, by H. A. Allard.

The Neanderthal Phase of Man, by Aleš Hrdlička.

Indian Costumes in the United States National Museum, by H. W. Krieger.

Mounds and Other Ancient Earthworks of the United States, by David I. Bushnell, jr.

Geocronology, by Gerard de Geer.

The Physiology of the Ductless Glands, by N. B. Taylor.

Arrhenius Memorial Lecture, by Sir James Walker.

Theodore William Richards, by Gregory P. Baxter.

SPECIAL PUBLICATIONS

Explorations and Field Work of the Smithsonian Institution in 1928. March 22, 1929. 198 pp., 173 text figs. (Publ. 3011.)

Classified list of Smithsonian Publications Available for Distribution, May 20, 1929. Compiled by Helen Munroe, 29 pp. (Publ. 3020.)

World Weather Records—Errata. By H. Helm Clayton. To accompany Smithsonian Miscellaneous Collections, volume 79. May 29, 1929. 28 pp. (Publ. 3019.)

REPRINTS

Handbook of the National Aircraft Collection. By Paul Edward Garber. Second edition, November, 1928. 32 pp., numerous illustrations.

Smithsonian Physical Tables. By Frederick E. Fowle. Seventh revised edition, fourth reprint, February 26, 1929. 458 pp. (Publ. 2539.)

Smithsonian Geographical Tables, By R. S. Woodward. Third edition, second reprint, August 17, 1929. 182 pp. (Publ. 854.)

PUBLICATIONS OF THE UNITED STATES NATIONAL MUSEUM

The editorial work of the National Museum is in the hands of Dr. Marcus Benjamin. During the year ending June 30, 1929, the Museum published 1 annual report, 2 volumes of proceedings, 4 complete bulletins, 1 part of a bulletin, 2 parts in the series Contributions from the United States National Herbarium, and 59 separates from the proceedings.

The issues of the bulletin were as follows:

Bulletin 100. Contributions to the Biology of the Philippine Archipelago and Adjacent Regions.

Volume 1. Papers on collections gathered by the *Albatross*, Philippine Expedition, 1907–1910.

Volume 8. The Fishes of the Series Capriformes, Ephippiformes, and Squamipennes, Collected by the United States Bureau of Fisheries Steamer *Albatross*, Chiefly in Philippine Seas and Adjacent Waters. By Henry W. Fowler and Barton A. Bean.

Bulletin 104. The Foraminifera of the Atlantic Ocean. Part 6. Miliolidae, Opthalmidiidae and Fischerinidae. By Joseph Augustine Cushman.

Bulletin 145. A Revision of the North American Species of Buprestid Beetles belonging to the Genus Agrilus. By W. S. Fisher.

Bulletin 146. Life Histories of North American Shore Birds. Order Limicolae (Part 2). By Arthur Cleveland Bent.

The issues of the Contributions from the United States National Herbarium were as follows:

Volume 26, part 3. Costa Rican Mosses collected by Paul C. Standley in 1924–1926. By Edwin B. Bartram.

Volume 28, part 1. The North American Species of Paspalum. By Agnes Chase.

Of the separates from the proceedings, 4 were from volume 73, 26 from volume 74, 25 from volume 75, and 4 from volume 76.

PUBLICATIONS OF THE BUREAU OF AMERICAN ETHNOLOGY

The editorial work has continued under the direction of the editor, Mr. Stanley Searles.

During the year three annual reports and five bulletins were issued.

Forty-first Annual Report. Accompanying papers: Coiled Basketry in British Columbia and Surrounding Region (Boas, assisted by Haeberlin, Teit, and Roberts); Two Prehistoric Villages in Middle Tennessee (Myer). 626 pp., 137 pls., 200 figs., 1 pocket map.

Forty-third Annual Report. Accompanying papers: The Osage Tribe; Two Versions of the Child-naming Rite (La Flesche); Wawenock Myth Texts from Maine (Speck); Native Tribes and Dialects of Connecticut, a Mohegan-Pequot Diary (Speck); Picuris Children's Stories (Harrington and Roberts); Iroquoian Cosmology—Second Part (Hewitt). 828 pp., 44 pls., 9 figs.

Forty-fourth Annual Report. Accompanying papers: Exploration of the Burton Mound at Santa Barbara, California (Harrington); Social and Religious Beliefs and Usages of the Chickasaw Indians (Swanton); Uses of Plants by the Chippewa Indians (Densmore); Archeological Investigations—II (Fowke). 555 pp., 98 pls., 16 figs.

Bulletin 84. Vocabulary of the Kiowa Language (Harrington). 255 pp., 1 fig.

Bulletin 86. Chippewa Customs (Densmore). 204 pp., 90 pls., 27 figs.

Bulletin 87. Notes on the Buffalo-head Dance of the Thunder Gens of the Fox Indians (Michelson). 94 pp., 1 fig.

Bulletin 89. Observations on the Thunder Dance of the Bear Gens of the Fox Indians (Michelson). 73 pp., 1 fig.

Bulletin 92. Shabik'eshchee Village: A Late Basket Maker Site in the Chaco Canyon, New Mexico (Roberts). 164 pp., 31 pls., 32 figs.

Publications in press are as follows:

Forty-fifth Annual Report. Accompanying papers: The Salishan Tribes of the Western Plateaus (Teit, edited by Boas); Tatooing and Face and Body Painting of the Thompson Indians, British Columbia (Teit, edited by Boas); The Ethnobotany of the Thompson Indians of British Columbia (Teit, edited by Steedman); The Osage Tribe; Rite of the Wa-xo-be (La Flesche).

Bulletin 88. Myths and Tales of the Southeastern Indians (Swanton).

Bulletin 90. Papago Music (Densmore).

Bulletin 91. Additional Studies of the Arts, Crafts, and Customs of the Guiana Indians, with special reference to those of Southeastern British Guiana (Roth).
Bulletin 93. Pawnee Music (Densmore).

REPORT OF THE AMERICAN HISTORICAL ASSOCIATION

The annual reports of the American Historical Association are transmitted by the association to the Secretary of the Smithsonian Institution and are communicated by him to Congress, as provided by the act of incorporation of the association.

The annual report for 1923 and the supplemental volume to the report for 1924 were issued during the year.

REPORT OF THE NATIONAL SOCIETY, DAUGHTERS OF THE AMERICAN REVOLUTION

The manuscript of the Thirty-first Annual Report of the National Society, Daughters of the American Revolution, was transmitted to Congress, in accordance with the law, December 6, 1928.

ALLOTMENTS FOR PRINTING

The congressional allotments for the printing of the Smithsonian Report to Congress and the various publications of the Government bureaus under the administration of the Institution were virtually used up at the close of the year. The appropriation for the coming year ending June 30, 1930, totals $95,000, allotted as follows:

Annual report to the Congress of the Board of Regents of the Smithsonian Institution	$11, 500
National Museum	46, 500
Bureau of American Ethnology	28, 300
National Gallery of Art	500
International Exchanges	300
International Catalogue of Scientific Literature	100
National Zoological Park	300
Astrophysical Observatory	500
Annual report of the American Historical Association	7, 000

SMITHSONIAN ADVISORY COMMITTEE ON PRINTING AND PUBLICATION

The editor has continued to serve as secretary of the Smithsonian advisory committee on printing and publication, to which are referred for consideration and recommendation all manuscripts offered to the Institution and its branches. The committee also considers matters of publication policy. Eight meetings were held during the year and 136 manuscripts acted upon. The membership at the close of the year was as follows: Dr. Leonhard Stejneger, head curator

of biology, National Museum, chairman; Dr. George P. Merrill, head curator of geology, National Museum; Mr. M. W. Stirling, chief, Bureau of American Ethnology; Dr. William M. Mann, director, National Zoological Park; Mr. W. P. True, editor of the Institution, secretary; Dr. Marcus Benjamin, editor of the National Museum; and Mr. Stanley Searles, editor of the Bureau of American Ethnology.

Respectfully submitted.

W. P. True, *Editor*.

Dr. Charles G. Abbot,
Secretary, Smithsonian Institution.

APPENDIX 12

LIST OF SUBSCRIBERS TO JAMES SMITHSON MEMORIAL EDITION, SMITHSONIAN SCIENTIFIC SERIES [1]

Mr. Harry T. Abernathy,
Kansas City, Mo.
Mr. Edward E. B. Adams,
New York, N. Y.
Miss Mary Barclay Adams,
Washington, D. C.
Mr. Eugene E. Ailes,
New York, N. Y.
Mr. John E. Aldred,
New York, N. Y.
Mr. J. Henry Alexandre,
New York, N. Y.
Mr. Walter H. Alford,
Kenosha, Wis.
Mr. Frederic W. Allen,
New York, N. Y.
Mr. Rayford W. Alley,
New York, N. Y.
Mr. E. G. Ames,
Seattle, Wash.
Mr. George S. Amory.
New York, N. Y.
Mr. E. A. Anderson,
Naugatuck, Conn.
Mr. John Anderson,
New York, N. Y.
Mr. Wendell W. Anderson,
Detroit, Mich.
Mr. W. J. Anderson,
New York, N. Y.
Mr. W. S. Andrews,
Syracuse, N. Y.
Mr. Hugh D. Auchincloss,
Washington, D. C.
Mr. Charles F. Ayer,
New York, N. Y.
Mr. Richard B. Ayer,
New York, N. Y.
Mr. Jules S. Bache,
New York, N. Y.
Mr. George W. Bacon,
New York, N. Y.
Mr. Franklin Baker, jr.,
Hoboken, N. J.
Mr. Charles F. Baldwin,
Appleton, Wis.
Mr. William D. Baldwin,
New York, N. Y.
Mr. Howard P. Ballantyne,
Detroit, Mich.
Mr. Louis Bamberger,
Newark, N. J.
Mr. Joseph Bancroft,
Wilmington, Del.
Mr. David Bandler,
New York, N. Y.
Mr. Edward J. Barber,
New York, N. Y.
Mr. Thomas Barbour,
Cambridge, Mass.
Mr. J. S. Barnes,
New York, N. Y.
Mr. Charles M. Barnett,
New York, N. Y.
Mr. Austin D. Barney,
Hartford, Conn.
Dr. Grant S. Barnhart,
Washington, D. C.
Mr. William S. Barstow,
New York, N. Y.
Mr. W. H. Barthold,
New York, N. Y.
Mr. Philip G. Bartlett,
New York, N. Y.
Mr. Charles E. Bascom,
St. Louis, Mo.
Mr. Harvey Bates, jr.,
Indianapolis, Ind.
Hon. Walter E. Batterson,
Hartford, Conn.

[1] List brought up to date as of Nov. 15, 1929.

Mr. Oliver G. Bauman,
Buffalo, N. Y.
Mr. Armistead Keith Baylor,
New York, N. Y.
Mr. J. N. Beckley,
Rochester, N. Y.
Mr. Barton A. Bean, jr.,
Buffalo, N. Y.
Dr. A. J. Beller,
New York, N. Y.
Mr. La Monte J. Belnap,
New York, N. Y.
Mr. Alfred M. Best,
New York, N. Y.
Mr. John P. Bickell,
Toronto, Canada.
Mr. Edwin Binney,
New York, N. Y.
Mr. Charles E. Birge,
New York, N. Y.
Mr. Clarence R. Bitting,
Detroit, Mich.
Mr. James Madison Blackwell,
New York, N. Y.
Mrs. Emmons Blaine,
Chicago, Ill.
Mrs. David H. Blair,
Washington, D. C.
Mr. Samuel Shipley Blood,
New York, N. Y.
Mrs. Elizabeth B. Blossom,
Cleveland, Ohio.
Mr. Albert Blum,
New York, N. Y.
Mr. Sidney Blumenthal,
New York, N. Y.
Mr. Samuel T. Bodine,
Philadelphia, Pa.
Mr. W. E. Boeing,
Seattle, Wash.
Mr. Lucius M. Boomer,
New York, N. Y.
Mr. L. C. Bootes,
Jackson, Mich.
Mr. C. Jackson Booth,
Hull, Quebec, Canada.
Mr. Edward F. Bosson,
Hartford, Conn.
Mr. Samuel H. Bowman, jr.,
Minneapolis, Minn.
Mrs. John C. Boyd,
Washington, D. C.
Mr. A. R. M. Boyle,
New York, N. Y.
Mr. F. W. Bradley,
San Francisco, Calif.
Mr. F. W. Braun,
Los Angeles, Calif.
Mr. Bradford Brinton,
New York, N. Y.
Mr. Henry Platt Bristol,
New York, N. Y.
Mr. Robert S. Brookings,
Washington, D. C.
Mr. Gerald Brooks,
New York, N. Y.
Mr. Donaldson Brown,
New York, N. Y.
Mr. H. F. Brown,
Wilmington, Del.
Mr. Hays R. Browning,
New York, N. Y.
Mr. Otto Brunenmeister, jr.,
New York, N. Y.
Mr. W. Gerald Bryant,
Bridgeport, Conn.
Mr. Albert Buchman,
New York, N. Y.
Mr. Britton I. Budd,
Chicago, Ill.
Mr. Lawrence D. Buhl,
Detroit, Mich.
Mr. F. Kingsbury Bull,
Litchfield, Conn.
Mr. Percy Bullard,
New York, N. Y.
Mr. W. Douglas Burden,
New York, N. Y.
Mr. Frederick John Burghard,
New York, N. Y.
Mrs. Stevenson Burke,
Cleveland, Ohio.
Mr. Eric Burkman,
New York, N. Y.
Mr. Gordon W. Burnham,
New York, N. Y.
Mrs. J. S. Burnside,
Toronto, Ontario, Canada.
Hon. Martin Burrell,
Ottawa, Canada.
Mr. Smith P. Burton, jr.,
Boston, Mass.
Mr. F. S. Byram (2 subscriptions),
Philadelphia, Pa.

Mr. James D. Callery,
Pittsburgh, Pa.
Mr. Jasper A. Campbell, jr.,
New York, N. Y.
Mr. John T. Campbell,
Norfolk, Va.
Mr. William Candler,
Atlanta, Ga.
Mr. Albert H. Canfield,
Bridgeport, Conn.
Mr. William C. Cannon,
New York, N. Y.
Mr. Martin Cantine,
New York, N. Y.
Mr. George W. Carnrick,
New York, N. Y.
Mr. James H. Carter,
New York, N. Y.
Mr. John J. Carty,
New York, N. Y.
Mr. George Cary,
Buffalo, N. Y.
Mr. Theodore W. Case,
Auburn, N. Y.
Mr. Thomas E. Casey,
New York, N. Y.
Mr. Charles A. Cass,
New York, N. Y.
Mrs. E. Crane Chadbourne,
Washington, D. C.
Mr. Harry Chandler,
Los Angeles, Calif.
Mr. Charles M. Chapin,
New York, N. Y.
Mr. C. Merrill Chapin, jr.,
New York, N. Y.
Mr. S. B. Chapin, jr.,
New York, N. Y.
Mr. A. Wallace Chauncey,
New York, N. Y.
Mr. Starling W. Childs,
New York, N. Y.
Mr. George H. Chisholm,
Buffalo, N. Y.
Mr. F. Edwin Church,
New York, N. Y.
Dr. A. Schuyler Clark,
New York, N. Y.
Mr. Eli P. Clark,
Los Angeles, Calif.
Mr. George H. Clark,
Rochester, N. Y.
Mr. Ray Clark,
New York, N. Y.
Mr. Robert Sterling Clark,
New York, N. Y.
Mr. W. A. Clark, III,
Los Angeles, Calif.
Mr. John L. Clawson,
Buffalo, N. Y.
Mr. Oliver M. Clifford,
St. Louis, Mo.
Mr. George I. Cochran,
Los Angeles, Calif.
Miss Ella S. Coe,
Litchfield, Conn.
Mr. C. W. Floyd Coffin,
New York, N. Y.
Dr. Wallace P. Cohoe,
New York, N. Y.
Mr. John N. Cole,
New York, N. Y.
Dr. Philip G. Cole,
Brooklyn, N. Y.
Mr. Viott Myers Cole,
New York, N. Y.
Mr. Philip S. Collins,
Philadelphia, Pa.
Mr. Martin Conboy,
New York, N. Y.
Mr. W. L. Conwell,
New York, N. Y.
Prof. Thomas F. Cooke,
Buffalo, N. Y.
Mr. T. J. Coolidge,
Boston, Mass.
Mr. Edward F. Coombs,
New York, N. Y.
Mr. Howard Coonley,
Boston, Mass.
Mrs. Q. F. Coonley,
Washington, D. C.
Mr. Dudley Martindale Cooper,
New York, N. Y.
Mr. W. S. Corby,
Washington, D. C.
Mr. Fred D. Corey,
Buffalo, N. Y.
Mr. John W. Cowper,
Buffalo, N. Y.
Mr. Alexander M. Crane,
New York, N. Y.
Mr. Clinton H. Crane,
New York, N. Y.

Mr. Gifford B. Crary,
Binghamton, N. Y.
Mr. William Nelson Cromwell,
New York, N. Y.
Mr. Franklin M. Crosby,
Minneapolis, Minn.
Mr. J. W. Cross,
New York, N. Y.
Mr. Miquel Cruchaga,
Paris, France.
Mr. E. A. Cudahy, jr.,
Chicago, Ill.
Mr. J. S. Cullinan,
Houston, Tex.
Mr. Victor M. Cutter,
Boston, Mass.
Mr. C. Suydam Cutting,
New York, N. Y.
Cuyamel Fruit Co.,
New Orleans, La.
Mr. Charles E. Dalrymple,
Newark, N. J.
Mr. U. de B. Daly,
St. Louis, Mo.
Mr. Ernest B. Dane,
Boston, Mass.
Dr. Frank E. Darling,
Milwaukee, Wis.
Mr. Daniel Darrow,
New York, N. Y.
Mr. Louis R. Davidson,
Buffalo, N. Y.
Señor Don Carlos G. Davila,
Washington, D. C.
Mr. Basil H. Davis,
New York, N. Y.
Mr. Edgar B. Davis,
New York, N. Y.
Mr. James Sherlock Davis,
Brooklyn, N. Y.
Mrs. T. B. Davis,
Rock Island, Ill.
Mr. Frederic A. Delano,
Washington, D. C.
Mr. William Adams Delano,
New York, N. Y.
Mr. Frank L. D'Elia,
Jersey City, N. J.
Mr. George Denégre,
New Orleans, La.
Mr. A. C. Deuel,
Niagara Falls, N. Y.
Mr. Fairman R. Dick,
New York, N. Y.

Mr. Albert H. Dickinson,
Kansas City, Mo.
Mr. Hunt T. Dickinson,
New York, N. Y.
Mr. Milton S. Dillon,
New York, N. Y.
Mr. Fitz Eugene Dixon,
Philadelphia, Pa.
Mr. S. C. Dobbs, jr.,
Atlanta, Ga.
Mr. Frank P. Doherty,
Los Angeles, Calif.
Mr. L. W. Dommerich,
New York, N. Y.
Mr. James P. Donahue,
New York, N. Y.
Mr. Robert Donner,
Buffalo, N. Y.
Dr. A. G. Doughty,
Ottawa, Canada.
Mr. Robert Douglas,
Rochester, N. Y.
Dr. George S. Drake,
St. Louis, Mo.
Mr. Dow H. Drukker,
Passaic, N. J.
Mr. Frank A. Dudley,
Niagara Falls, N. Y.
Mr. Caleb C. Dula,
New York, N. Y.
Mr. A. E. Duncan,
Baltimore, Md.
Mrs. Jessie D. Dunlap,
Toronto, Canada.
Mr. Eugene E. du Pont,
Wilmington, Del.
Mr. Henry B. du Pont,
Wilmington, Del.
Mr. Irenee du Pont,
Wilmington, Del.
Mrs. J. Coleman du Pont,
New York, N. Y.
Mr. Lammot du Pont,
Wilmington, Del.
Mr. S. Hallock du Pont,
Wilmington, Del.
Mr. Arthur S. Dwight,
New York, N. Y.
Mr. Herbert T. Dyett,
Rome, N. Y.
Mr. Chaffee Earle,
Los Angeles, Calif.
Mr. Thomas T. Eason,
Enid, Okla.

Lady Eaton,
Toronto, Canada.
Dr. George J. Eckel,
Buffalo, N. Y.
Mr. George H. Eddy,
Kenosha, Wis.
Mr. James G. Eddy,
Seattle, Wash.
Hon. Gordon C. Edwards,
Ottawa, Canada.
Mr. Louis J. Ehret (2 subscriptions),
New York, N. Y.
Mr. Otto M. Eidlitz,
New York, N. Y.
Mr. Arturo M. Elias,
New York, N. Y.
Mr. George Adams Ellis,
New York, N. Y.
Mr. Duncan Steuart Ellsworth,
New York, N. Y.
Mr. Albert C. Elser,
Milwaukee, Wis.
Mr. George W. Ely,
New York, N. Y.
Mr. James Radford English,
New York, N. Y.
Mr. William Phelps Eno,
Washington, D. C.
Mr. W. H. Erhart,
New York, N. Y.
Mr. Joseph Errington,
Toronto, Canada.
Mr. W. H. Eshbaugh,
New York, N. Y.
Mr. Nathaniel I. Evens,
New York, N. Y.
Mr. Edward A. Everett,
Long Island City, N. Y.
Mr. George A. Eyer,
New York, N. Y.
Mr. Charles S. Eytinge,
New York, N. Y.
Mr. Eberhard Faber,
New York, N. Y.
Mr. Frank J. Fahey,
Boston, Mass.
Mrs. Gibson Fahnestock,
Washington, D. C.
Mr. Douglas Fairbanks,
Hollywood, Calif.
Mr. Arthur W. Fairchild,
Milwaukee, Wis.
Mr. Herman W. Falk,
Milwaukee, Wis.
Miss Catherine Farrar,
Paterson, N. J.
Mr. James A. Farrell,
New York, N. Y.
Mr. George R. Fearing,
Boston, Mass.
Mr. L. F. Fedders,
Buffalo, N. Y.
Mr. Edwin C. Feigenspan,
Newark, N. J.
Mr. Orestes Ferrara,
Washington, D. C.
Mr. John E. N. Figved,
Milwaukee, Wis.
Dr. Mark E. Finley,
Washington, D. C.
Mr. Thomas W. Finucane,
Rochester, N. Y.
Mr. Harvey S. Firestone,
Akron, Ohio.
Mr. Alfred J. Fisher,
Detroit, Mich.
Mr. Charles T. Fisher,
Detroit, Mich.
Mr. Edward F. Fisher (2 subscriptions),
Detroit, Mich.
Mr. Frank C. Fisher,
New York, N. Y.
Mr. Fred J. Fisher,
Detroit, Mich.
Mr. Lawrence P. Fisher,
Detroit, Mich.
Mr. William A. Fisher,
Detroit, Mich.
Mr. B. F. Fitch,
New York, N. Y.
Mr. W. W. Flowers,
New York, N. Y.
Mr. Oscar G. Foellinger,
Fort Wayne, Ind.
Mr. R. W. Foote,
New Haven, Conn.
Mr. John B. Ford, jr.,
Detroit, Mich.
Mr. S. W. Fordyce,
St. Louis, Mo.
Mr. Oswald Fowler,
New York, N. Y.
Mr. Richard L. Fox,
Philadelphia, Pa.
Mr. Charles B. Francis,
St. Louis, Mo.
Mr. Clayton E. Freeman,
New York, N. Y.

Mrs. Emma B. French,
Manchester, N. Y.
Mr. Herbert G. French,
Cincinnati, Ohio.
Mr. Robert E. Friend,
Milwaukee, Wis.
Mr. John Hemming Fry,
New York, N. Y.
Dr. L. A. Fuerstenau,
Milwaukee, Wis.
Dr. Eugene Fuller,
Seattle, Wash.
Mr. Frederick J. Fuller,
New York, N. Y.
Mr. George F. Fuller,
Worcester, Mass.
Mr. Walter D. Fuller,
Philadelphia, Pa.
Mr. William Shirley Fulton,
Waterbury, Conn.
Judge Arthur G. Gallagher,
New York, N. Y.
Mr. Frank de Ganahl,
New York, N. Y.
Mr. John W. Garrett,
Baltimore, Md.
Mr. Paul Willard Garrett,
New York, N. Y.
Mr. James L. Gartner,
Tulsa, Okla.
Mr. A. O. Gates,
New Haven, Conn.
Mr. Charles R. Gay,
New York, N. Y.
Mr. C. P. Gearon,
New York, N. Y.
Mr. Stanley L. Gedney, jr.,
East Orange, N. J.
Mr. Paulino Gerli,
New York, N. Y.
Mr. James L. Gerry,
New York, N. Y.
Mr. William P. Gest,
Philadelphia, Pa.
Mrs. Milton E. Getz,
Beverly Hills, Calif.
Mrs. John H. Gibbons,
Washington, D. C.
Mr. Edward E. Gillen,
Milwaukee, Wis.
Mr. Michael Gioe, sr.,
New York, N. Y.
Mr. Charles F. Glore,
Chicago, Ill.
Hon. Guy D. Goff,
Washington, D. C.
Mr. Richard J. Goodman,
Hartford, Conn.
Mr. Edward S. Goodwin,
Hartford, Conn.
Mr. Jose E. Gorrin,
Habana, Cuba.
Mr. Osmer N. Gorton,
New York, N. Y.
Mr. Chauncey P. Goss, jr.,
Waterbury, Conn.
Mr. Edward O. Goss,
Waterbury, Conn.
Mr. George A. Goss,
Waterbury, Conn.
Mr. John H. Goss,
Waterbury, Conn.
Mr. Lyttleton B. P. Gould,
New York, N. Y.
Mr. William B. Gourley,
Paterson, N. J.
Mr. S. C. Graham,
Los Angeles, Calif.
Mr. Alfred E. Green,
Hollywood, Calif.
Mr. George F. Green,
Danbury, Conn.
Mr. Lincoln Green,
Washington, D. C.
Dr. Louis S. Greene,
Washington, D. C.
Dr. James C. Greenway,
New Haven, Conn.
Mr. David L. Grey,
St. Louis, Mo.
Mr. John Gribbell (5 subscriptions),
Philadelphia, Pa.
Mr. B. J. Grigsby,
Chicago, Ill.
Mr. George B. Grinnell,
New York, N. Y.
Mrs. Minnie Tillou Grippin,
Bridgeport, Conn.
Mr. B. Howell Griswold, jr.,
Baltimore, Md.
Mr. Edgar J. Griswold,
New York, N. Y.
Grosvenor Library,
Buffalo, N. Y.
(Presented by Mr. Ansley Wilcox, Mr. William Schoellkopf, Mr. H. W. Wolcott, Mr. Percy G. Lapey, Mr. Edward L. Jellinek, Buffalo, N. Y.)

Mr. Allen D. Gutchess,
Toledo, Ohio.
Mr. Charles W. Guttzeit,
New York, N. Y.
Mr. Robert E. Hackett,
Milwaukee, Wis.
Mr. Fred H. Haggerson,
New York, N. Y.
Mr. Robert L. Hague,
New York, N. Y.
Mr. Edward A. Halbleib,
Rochester, N. Y.
Mr. Mayer L. Halff,
New York, N. Y.
Mr. E. K. Hall,
New York, N. Y.
Mr. William A. Hamann,
New York, N. Y.
Mr. Joseph G. Hamblen, jr.,
Detroit, Mich.
Mr. Chauncey J. Hamlin,
Buffalo, N. Y.
Mr. J. E. Hammell,
Toronto, Canada.
Mr. John Hays Hammond,
New York, N. Y.
Mrs. C. E. Hancock,
Syracuse, N. Y.
Dr. Walter S. Harban,
Washington, D. C.
Mr. W. Albert Harbison,
New York, N. Y.
Mr. Acheson A. Harden,
Passaic, N. J.
Mr. John R. Hardin,
Newark, N. J.
Mr. Louis A. Harding,
Buffalo, N. Y.
Mr. Franklin Hardinge,
Chicago, Ill.
Mr. J. B. Hardon,
Boston, Mass.
Mr. Huntington R. Hardwick,
Boston, Mass.
Mr. Anton G. Hardy,
New York, N. Y.
Mr. D. W. Hardy,
New York, N. Y.
Mr. Bruce H. Harlton,
Tulsa, Okla.
Mr. Rawson B. Harmon,
Detroit, Mich.
Mr. Henry Harnischfeger,
Milwaukee, Wis.
Dr. James T. Harrington,
Poughkeepsie, N. Y.
Mr. Gordon L. Harris,
New York, N. Y.
Mr. William Harris,
Totawa, N. J.
Mr. Alfred Hart,
Waterbury, Conn.
Mr. Barton Haselton,
Rome, N. Y.
Mr. Philip H. Haselton,
New York, N. Y.
Dr. F. R. Haussling,
Newark, N. J.
Mr. Horace Havemeyer,
New York, N. Y.
Mr. Elmer H. Havens,
Bridgeport, Conn.
Dr. George Waller Hawley,
Bridgeport, Conn.
Mr. Samuel W. Hayes,
Oklahoma City, Okla.
Mr. George Hearst,
San Francisco, Calif.
Mr. Roy W. Hemingway,
Auburn, N. Y.
Mr. F. R. Henderson,
New York, N. Y.
Mrs. A. Barton Hepburn,
New York, N. Y.
Mr. Henry Herbermann,
New York, N. Y.
Mr. Milton S. Hershey,
Hershey, Pa.
Mr. Jean Hersholt,
Beverly Hills, Calif.
Mrs. Sallie A. Hert,
Louisville, Ky.
Mr. Reginald Hess,
New York, N. Y.
Mr. Francis Lee Higginson,
Boston, Mass.
Mr. C. A. Hight,
Boston, Mass.
Mr. Joseph H. Himes,
Washington, D. C.

Mr. Edward Hines,
Chicago, Ill.
Mr. Lewis A. Hird,
New York, N. Y.
Mr. Arthur L. Hobson,
Boston, Mass.
Mrs. Grace Whitney Hoff,
Washington, D. C.
Mr. Albert L. Hoffman,
New York, N. Y.
Mr. Samuel V. Hoffman,
New York, N. Y.
Mr. William F. Hoffman,
Newark, N. J.
Mrs. Edward Holbrook,
New York, N. Y.
Mr. Joshua B. Holden,
Boston, Mass.
Mr. William J. Holliday,
Indianapolis, Ind.
Mr. Edward J. Holmes,
Boston, Mass.
Mr. George E. Holmes,
New York, N. Y.
Mr. W. R. G. Holt,
Montreal, Canada.
Mr. Ernest Hopkinson,
New York, N. Y.
Mr. Louis J. Horowitz,
New York, N. Y.
Mr. John S. A. Hosford,
New York, N. Y.
Miss Marie O. Hotchkiss,
East River, Conn.
Mr. W. Deering Howe,
New York, N. Y.
Mr. Allen G. Hoyt,
New York, N. Y.
Mr. Richard F. Hoyt,
New York, N. Y.
Hon. Charles E. Hughes,
New York, N. Y.
Mr. Felix T. Hughes,
New York, N. Y.
Mrs. Margarita Cress Hunt,
Washington, D. C.
Mr. Frederick H. Hurdman,
New York, N. Y.
Mr. E. F. Hutton,
New York, N. Y.
Mr. R. J. H. Hutton,
Buffalo, N. Y.
Mr. William Dunn Hutton,
New York, N. Y.
Mr. A. F. Hyde,
New York, N. Y.
Dr. Edmund W. Ill,
Newark, N. J.
Mr. Charles H. Innes,
Boston, Mass.
Mr. Samuel Insull,
Chicago, Ill.
Mr. Robert F. Irwin, jr.,
Philadelphia, Pa.
Mr. Henry H. Jackson,
New York, N. Y.
Mr. Stanley P. Jadwin,
New York, N. Y.
Mr. Alfred W. Jenkins,
New York, N. Y.
Miss Mary E. Jenkins,
Syracuse, N. Y.
Mr. Ulysses S. Jenkins,
Chicago, Ill.
Mrs. Mary L. Jennings,
Washington, D. C.
Mr. E. J. Johnson,
Detroit, Mich.
Mr. Eldridge R. Johnson,
Camden, N. J.
Mr. James A. Johnson,
Buffalo, N. Y.
Mr. Robert McK. Jones,
St. Louis, Mo.
Mr. Stephen R. Jones,
New York, N. Y.
Miss Grace Jordan,
Peekskill, N. Y.
Mr. R. J. Jowsey,
Toronto, Canada.
Mr. George H. Judd,
Washington, D. C.
Miss Katherine Judge,
Washington, D. C.
Mr. Gilbert W. Kahn,
New York, N. Y.
Mr. Otto H. Kahn,
New York, N. Y.
Mr. Henry J. Kaltenbach,
New York, N. Y.
Mr. Foxhall P. Keene,
New York, N. Y.
Mr. Russell M. Keith,
Cleveland, Ohio.

Mr. Arthur M. Kelley,
Bayshore, L. I., N. Y.
Dr. Foster Kennedy,
New York, N. Y.
Mr. A. Atwater Kent,
Philadelphia, Pa.
Mr. Marshall R. Kernochan,
Tuxedo Park, N. Y.
Mr. C. C. Kerr,
New York, N. Y.
Mr. W. W. Kincaid,
Niagara Falls, N. Y.
Mr. Willey Lyon Kingsley,
Rome, N. Y.
Mr. W. Ruloff Kip,
New York, N. Y.
Mr. William F. Kip,
New York, N. Y.
Mr. Gustavus T. Kirby,
New York, N. Y.
Dr. Edward H. Kirschbaum,
Waterbury, Conn.
Mr. Benjamin Kittinger,
Buffalo, N. Y.
Mr. John K. Kline,
Green Bay, Wis.
Mr. Joseph F. Knapp,
New York, N. Y.
Mr. Harry French Knight,
St. Louis, Mo.
Mr. W. W. Knight,
Toledo, Ohio.
Mr. Seymour H. Knox,
Buffalo, N. Y.
Mr. Philip A. Koehring,
Milwaukee, Wis.
Mr. Walter F. Koken,
St. Louis, Mo.
Mr. Edward L. Koons,
Buffalo, N. Y.
Mr. J. N. Korhumel,
Cicero, Ill.
Mr. Harry G. Kosch,
New York, N. Y.
Mr. Frederick J. Koster,
San Francisco, Calif.
Mr. de Lancey Kountze,
New York, N. Y.
Mr. J. L. Kraft,
Chicago, Ill.
Dr. Shepard Krech,
New York, N. Y.
Mrs. Anna E. Kresge,
Detroit, Mich.
Mr. Stanley S. Kresge (3 subscriptions),
Detroit, Mich.
Mr. Arthur W. Kretschmar,
New York, N. Y.
Mr. L. Kuehn,
Milwaukee, Wis.
Mr. Gerard Kuehne,
New York, N. Y.
Mr. Felix Lake,
Washington, D. C.
Mr. H. C. Lakin,
New York, N. Y.
Mr. R. P. Lamont,
Chicago, Ill.
Mrs. Marshall Langhorne,
Washington, D. C.
Mr. Henry G. Lapham,
Boston, Mass.
Mr. Sylvester P. Larkin,
New York, N. Y.
Mr. Irwin B. Laughlin,
Washington, D. C.
Mr. Eugene B. Lawson,
Tulsa, Okla.
Mr. John S. Leahy,
St. Louis, Mo.
Mrs. L. A. Lefevre,
Vancouver, British Columbia.
Mr. Erich E. Lehsten,
New York, N. Y.
Mr. William H. Leland,
Worcester, Mass.
Miss Isobel Lenman (2 subscriptions),
Washington, D. C.
Mr. C. H. LeRoy,
New York, N. Y.
Mr. William Leslie,
New York, N. Y.
Mrs. Frank Letts,
Washington, D. C.
Mr. William E. Levis,
Alton, Ill.
Mr. Edwin C. Lewis,
Detroit, Mich.
Mr. Henry Lewis,
New York, N. Y.
Mr. Samuel A. Lewisohn,
New York, N. Y.

Mr. Louis K. Liggett,
Boston, Mass.
Mr. Josiah K. Lilly,
Indianapolis, Ind.
Mr. Josiah K. Lilly, jr.,
Indianapolis, Ind.
Mrs. Robert T. Lincoln,
Washington, D. C.
Mr. John S. Linen,
New York, N. Y.
Mr. James Duane Livingston,
New York, N. Y.
Mr. Horatio G. Lloyd,
Philadelphia, Pa.
Mr. S. D. Locke,
Bridgeport, Conn.
Mr. Ray Long,
New York, N. Y.
Mr. Frank Lord,
New York, N. Y.
Mr. James Taber Loree,
Albany, N. Y.
Dr. Earl P. Lothrop,
Buffalo, N. Y.
Mr. Charles E. Lotte,
Paterson, N. J.
Mr. F. W. Lovejoy,
Rochester, N. Y.
Mr. Horace Lowry,
Minneapolis, Minn.
Mr. C. T. Ludington,
Philadelphia, Pa.
Mr. Charles W. Luke,
New York, N. Y.
Mr. G. R. Lyman,
New York, N. Y.
Mr. James Lynah,
Detroit, Mich.
Mr. Grant S. Macartney,
St. Paul, Minn.
Mr. Norman E. Mack,
Buffalo, N. Y.
Mr. Malcolm S. Mackay,
New York, N. Y.
Mr. Carleton Macy,
New York, N. Y.
Mr. Clifford D. Mallory,
New York, N. Y.
Mr. W. E. Mallory,
Danbury, Conn.
Mr. Peter J. Maloney, jr.,
New York, N. Y.
Judge Francis X. Mancusco,
New York, N. Y.
Mr. Clayton Mark,
Chicago, Ill.
Mr. John Markle,
New York, N. Y.
Mr. Lawrence M. Marks,
New York, N. Y.
Mr. Howard C. Marmon,
Indianapolis, Ind.
Mr. Walter C. Marmon,
Indianapolis, Ind.
Mr. M. Lee Marshall,
New York, N. Y.
Mr. Richard H. Marshall,
New York, N. Y.
Mr. Bradley Martin,
New York, N. Y.
Mr. Darwin D. Martin,
Buffalo, N. Y.
Mr. John C. Martin,
Philadelphia, Pa.
Dr. Philip Marvel, sr.,
Atlantic City, N. J.
Mr. George Grant Mason,
New York, N. Y.
Mr. J. W. Mason,
San Francisco, Calif.
Mr. B. A. Massee,
Chicago, Ill.
Mr. Gordon M. Mather,
Toledo, Ohio.
Mrs. Grace H. Mather,
Cleveland, Ohio.
Mrs. G. E. Matthies,
Seymour, Conn.
Miss Katherine Matthies,
Seymour, Conn.
Mr. C. H. Matthiessen, jr.,
New York, N. Y.
Mr. Frank Matthiessen,
Chicago, Ill.
Mr. William L. Mauran,
Providence, R. I.
Mr. Howard W. Maxwell, jr.,
New York, N. Y.
Mr. Ambrose Farroll McCabe,
New York, N. Y.
Mr. Ormond William McClave,
New York, N. Y.
Mr. Kenner McConnell,
Columbus, Ohio.

Mr. James D. McCormack,
Vancouver, British Columbia.
Mr. Cyrus H. McCormick,
Chicago, Ill.
Mr. Leander McCormick-Goodhart,
Washington, D. C.
Mr. Alex W. McCoy,
Ponca City, Okla.
Mr. Henry Forbes McCreery,
New York, N. Y.
Mr. Hubert McDonnell,
New York, N. Y.
Mr. Frank H. McGraw,
New York, N. Y.
Mr. James H. McGraw,
New York, N. Y.
Mr. Sumner T. McKnight,
Minneapolis, Minn.
Mr. R. S. McLaughlin,
Ontario, Canada.
Mr. Marrs McLean,
Beaumont, Tex.
Mr. William L. McLean,
Philadelphia, Pa.
Mr. Clifford L. McMillen,
Milwaukee, Wis.
Mr. Andrew W. Mellon,
Washington, D. C.
Mr. Louis Mendelssohn,
Detroit, Mich.
Mr. Buckingham P. Merriman,
Waterbury, Conn.
Miss Ethel Douglas Merritt,
Washington, D. C.
Mr. William B. Mershon,
Saginaw, Mich.
Mr. A. H. Mertzanoff,
New York, N. Y.
Col. Herman A. Metz,
New York, N. Y.
Mr. Cord Meyer,
New York, N. Y.
Mr. Devereux Milburn,
New York, N. Y.
Mr. C. Wilbur Miller,
Baltimore, Md.
Mr. Ernest B. Miller,
Baltimore, Md.
Mr. John J. Miller,
Washington, D. C.
Dr. S. M. Milliken,
New York, N. Y.
Mr. Ogden L. Mills,
New York, N. Y.
Mr. Edward G. Miner,
Rochester, N. Y.
Mrs. F. B. Miner,
Flint, Mich.
Mr. John J. Mitchell,
Chicago, Ill.
Mr. Leeds Mitchell,
Chicago, Ill.
Mr. Roscoe R. Mitchell,
Buffalo, N. Y.
Mr. T. E. Mitten,
Philadelphia, Pa.
Mr. J. A. Moffett,
New York, N. Y.
Mr. Joseph A. Moller,
New York, N. Y.
Mr. Jay R. Monroe,
Orange, N. J.
Mr. Henry E. Montgomery,
Buffalo, N. Y.
Mr. William Moore,
Detroit, Mich,
Mr. Adelbert Moot,
Buffalo, N. Y.
Mrs. James Dudley Morgan,
Chevy Chase, Md.
Mr. J. Pierpont Morgan (2 subscriptions),
New York, N. Y.
Mr. John W. Morgan,
New York, N. Y.
Mrs. Edna Grippin Morris,
Bridgeport, Conn.
Mr. W. Cullen Morris,
New York, N. Y.
Mr. J. P. Muller,
New York, N. Y.
Mr. Samuel Mundheim,
New York, N. Y.
Mr. Frank C. Munson,
New York, N. Y.
Mr. C. Haywood Murphy,
Detroit, Mich.
Mr. Henry A. Murray,
New York, N. Y.
Premier Benito Mussolini,
Rome, Italy.
Mr. Harold Nathan,
New York, N. Y.
National Gallery of Art,
Washington, D. C.
National Library of Wales,
Wales.

Mr. John S. Newberry,
Detroit, Mich.
Hon. Truman H. Newberry,
Detroit, Mich.
Mr. Waldo Newcomer,
Baltimore, Md.
Mr. F. T. Nicholson,
New York, N. Y.
Mr. William E. Nickerson,
Boston, Mass.
Mr. John B. Niven,
New York, N. Y.
Mr. Aaron E. Norman,
New York, N. Y.
Mr. George W. Norris,
Philadelphia, Pa.
Mr. Harry Oakes,
Ontario, Canada.
Mr. J. J. O'Brien,
Chicago, Ill.
Mr. Lyle H. Olson,
New York, N. Y.
Mr. John Omwake,
Cincinnati, Ohio.
Mr. W. O'Neil,
Arkon, Ohio.
Mr. James L. O'Neill,
New York, N. Y.
Mr. Joseph E. Otis,
Chicago, Ill.
Mr. Roy H. Ott,
New York, N. Y.
Mr. Arthur Newton Pack,
Washington, D. C.
Mr. John F. Palmer,
Pawhuska, Okla.
Mr. Charles A. Parcells,
Detroit, Mich.
Mr. Earle W. Parcells,
Detroit, Mich.
Mr. George Pariot,
New York, N. Y.
Mr. Dale M. Parker,
New York, N. Y.
Mr. Henry Herbert Parmelee,
Paterson, N. J.
Mr. James Parmelee,
Washington, D. C.
Mr. Reginald H. Parsons,
Seattle, Wash.
Mr. William D. Patten,
New York, N. Y.
Mr. Stephen Paul,
New York, N. Y.
Mr. Charles S. Payson,
New York, N. Y.
Mr. Max H. Peiler,
Hartford, Conn.
Mr. Howland H. Pell,
New York, N. Y.
Mr. Charles Pfeiffer,
New York, N. Y.
Mr. Gustavus A. Pfeiffer,
New York, N. Y.
Mr. Knox B. Phagan,
New York, N. Y.
Mr. Leopold Philipp,
New York, N. Y.
Mr. Ellis L. Phillips,
New York, N. Y.
Mr. Rowley W. Phillips,
Waterbury, Conn.
Mrs. Thomas W. Phillips,
Washington, D. C.
Mr. Howard Phipps,
New York, N. Y.
Mr. H. M. Pierce,
Wilmington, Del.
Mr. Robert L. Pierrepont,
New York, N. Y.
Mr. William S. Pilling,
Philadelphia, Pa.
Mr. Townsend Pinkney,
New York, N. Y.
Mr. Bayard F. Pope,
New York, N. Y.
Mr. Frederick J. Pope,
New York, N. Y.
Mr. Joseph F. Porter,
Kansas City, Mo.
Mr. Joseph W. Powdrell,
Boston, Mass.
Mr. Herbert L. Pratt,
New York, N. Y.
Mrs. John T. Pratt,
New York, N. Y.
Mr. Sydney I. Prescott,
New York, N. Y.
Mr. William Cooper Procter,
Cincinnati, Ohio.
Mr. Thomas E. Proctor, 2d,
Boston, Mass.
Mr. Ralph Pulitzer,
New York, N. Y.
Mr. Percy R. Pyne, jr.,
New York, N. Y.
Mr. Ernest E. Quantrell,
New York, N. Y.

Mr. Edgar M. Queeny,
St. Louis, Mo.
Mr. Gershom T. Randall,
New York, N. Y.
Mr. de Lancey Rankine,
Niagara Falls, N. Y.
Mr. John J. Raskob,
New York, N. Y.
Mr. William F. Raskob,
Wilmington, Del.
Mr. Duncan H. Read,
New York, N. Y.
Mr. Earle H. Reynolds,
Chicago, Ill.
Mr. Harrison G. Reynolds,
Boston, Mass.
Mr. Edwin T. Rice,
New York, N. Y.
Mr. Neil W. Rice,
Boston, Mass.
Mr. S. Willson Richards,
New York, N. Y.
Mr. E. Ridgeway,
Chicago, Ill.
Mr. Harry G. Rieger,
Philadelphia, Pa.
Mr. Charles E. Riley,
Boston, Mass.
Mr. Arthur W. Rinke,
New York, N. Y.
Mrs. Anita Bell Ritter,
Washington, D. C.
Dr. William C. Rives,
Washington, D. C.
Mr. Walter B. Robb,
Buffalo, N. Y.
Mr. Owen F. Roberts,
New York, N. Y.
Mr. Irving E. Robertson,
Toronto, Canada.
Mr. William A. Rockefeller,
New York, N. Y.
Mrs. John A. Roebling,
Bernardsville, N. J.
Mr. Charles H. Roemer,
Paterson, N. J.
Mr. Saul E. Rogers,
New York, N. Y.
Mr. William H. Rollinson,
New York, N. Y.
Mr. Irving I. Rosenbaum,
New York, N. Y.
Mr. Edward L. Rossiter,
New York, N. Y.
Mr. Stanley A. Russell,
New York, N. Y.
Mr. William Hamilton Russell,
New York, N. Y.
Mrs. John Rutherford,
Washington, D. C.
Mr. W. R. Sampson,
Boston, Mass.
Mr. Henry Gansevoort Sanford,
New York, N. Y.
Mr. Harold A. Sands,
New York, N. Y.
Mr. James Savage,
Buffalo, N. Y.
Mr. Homer E. Sawyer,
New York, N. Y.
Mr. Michael A. Scatuorchio,
Jersey City, N. J.
Mr. Bernhard K. Schaefer,
New York, N. Y.
Mr. H. W. Schaefer,
New York, N. Y.
Mr. Herrman A. Schatz,
Poughkeepsie, N. Y.
Mr. William N. Schill,
New York, N. Y.
Mr. George Schmidt, jr.,
Elizabeth, N. J.
Mr. L. O. Schmidt,
New York, N. Y.
Mr. Daniel Schnakenberg,
New York, N. Y.
Mr. Henry Schniewind,
New York, N. Y.
Mr. Alfred H. Schoellkopf,
Buffalo, N. Y.
Mr. J. F. Schoellkopf, jr.,
Buffalo, N. Y.
Mr. Paul A. Schoellkopf,
Buffalo, N. Y.
Mr. Sherman W. Scofield,
Cleveland, Ohio.
Mr. T. A. Scott,
New York, N. Y.
Mr. William Keith Scott,
Los Angeles, Calif.
Mr. William E. Scripps,
Detroit, Mich.
Mr. Harold H. Seaman,
Milwaukee, Wis.
Mr. Frank A. Seiberling,
Akron, Ohio.
Mr. Walter Seligman,
New York, N. Y.

Mr. Jere A. Sexton,
New York, N. Y.
Mr. John C. Shaffer,
Chicago, Ill.
Mr. Richard Sharpe,
Wilkes-Barre, Pa.
Mr. G. Howland Shaw,
Washington, D. C.
Mr. Robert Alfred Shaw,
New York, N. Y.
Mr. Edward W. Sheldon,
New York, N. Y.
Mr. Harry E. Sheldon,
Pittsburgh, Pa.
Mrs. Charles R. Shepard,
Washington, D. C.
Mr. Frank P. Shepard,
New York, N. Y.
Mr. Roger B. Shepard,
St. Paul, Minn.
Mr. Robert W. Sherwin,
New York, N. Y.
Mrs. Paula W. Siedenburg,
Greenwich, Conn.
Mr. E. H. H. Simmons,
New York, N. Y.
Mrs. Frances G. Simmons,
Greenwich, Conn.
Mr. Z. G. Simmons, jr.,
New York, N. Y.
Mr. Robert E. Simon,
New York, N. Y.
Mr. F. H. Sisson,
New York, N. Y.
Mr. Louis Sloss,
San Francisco, Calif.
Mr. Andrew R. Smith,
Bridgeport, Conn.
Mr. E. A. Cappelan Smith,
New York, N. Y.
Dr. Edward W. Smith,
Meriden, Conn.
Mr. Frank Hill Smith,
Dayton, Ohio.
Mr. Glenn J. Smith,
Tulsa, Okla.
Mr. Julian C. Smith,
Montreal, Canada.
Mr. W. Hinckle Smith,
Philadelphia, Pa.
Mr. Winfred L. Smith,
New York, N. Y.
Mr. W. T. Sampson Smith,
New York, N. Y.
Mr. F. L. Smithe,
New York, N. Y.
Mr. John S. Snelham,
New York, N. Y.
Mr. Sidney H. Sonn,
New York, N. Y.
Mr. T. H. Soren,
Hartford, Conn.
Mr. Henry P. Spafard,
Hartford, Conn.
Maj. Lorillard Spencer,
New York, N. Y.
Mr. John R. Sproul,
Philadelphia, Pa.
Col. W. C. Spruance,
Wilmington, Del.
Dr. Edward H. Squibb,
Brooklyn, N. Y.
Mr. Andrew Squire (2 subscriptions),
Cleveland, Ohio.
Mr. Pierpont Langley Stackpole,
Boston, Mass.
Mr. William Hyde Stalker,
Toledo, Ohio.
Dr. A. Camp Stanley,
Washington, D. C.
Mr. H. J. L. Stark,
Orange, Tex.
Mr. Walter R. Steiner,
Hartford, Conn.
Mr. R. S. Sterling,
Houston, Tex.
Mr. Morris Stern,
Milwaukee, Wis.
Mr. Joseph E. Sterrett,
New York, N. Y.
Mr. Aron Steuer,
New York, N. Y.
Mr. Francis K. Stevens,
New York, N. Y.
Mr. J. Crawford Stevens,
White Plains, N. Y.
Mr. John P. Stevens,
New York, N. Y.
Mr. Walther A. Stiefel,
New York, N. Y.
Mr. Philip Stockton,
Boston, Mass.
Mr. Robert G. Stone,
Boston, Mass.
Mr. James J. Storrow, jr.,
Boston, Mass.
Mr. D. H. Strachan,
New York, N. Y.

Mr. Robert A. Stranahan,
Toledo, Ohio.
Mr. Silas H. Strawn,
Chicago, Ill.
Mr. Alvah G. Strong,
Rochester, N. Y.
Mrs. Hattie M. Strong,
Washington, D. C.
Mr. Walter A. Strong,
Chicago, Ill.
Mr. W. G. Stuber,
Rochester, N. Y.
Mr. Clement Studebaker, jr.,
Chicago, Ill.
Mr. Ernest Sturm,
New York, N. Y.
Mr. Charles L. Sturtevant,
Washington, D. C.
Mr. Samuel B. Sutphin,
Indianapolis, Ind.
Mr. R. O. Sweezey,
Montreal, Canada.
Countess Laszlo Szechenyi,
Washington, D. C.
Mr. Edgar W. Tait,
Pittsburgh, Pa.
Mr. Ralph L. Talbot,
Bridgeport, Conn.
Mr. Gerard P. Tameling,
New York, N. Y.
Mr. Edmund C. Tarbell,
New Castle, N. H.
Mr. Charles H. Taylor,
Boston, Mass.
Mr. Harden F. Taylor,
New York, N. Y.
Mr. Myron C. Taylor,
New York, N. Y.
Mr. Daniel G. Tenney,
New York, N. Y.
Mr. Alton T. Terrell,
Ansonia, Conn.
Mr. Arthur Van Rensselear Thompson,
New York, N. Y.
Mr. George W. Thompson,
New York, N. Y.
Mr. John R. Thompson, jr.,
Chicago, Ill.
Mr. Ralph E. Thompson,
Boston, Mass.
Mr. Robert M. Thompson (2 subscriptions),
New York, N. Y.
Mrs. William Reed Thompson,
Pittsburgh, Pa.
Mr. S. C. Thomson,
New York, N. Y.
Mr. J. C. Thorn,
New York, N. Y.
Mr. Francis B. Thorne,
New York, N. Y.
Dr. Edward C. Tilman,
New York, N. Y.
Mr. Charles E. Titchener,
Binghamton, N. Y.
Mr. Frederick M. Tobin,
Rochester, N. Y.
Mr. Roy E. Tomlinson,
New York, N. Y.
Mr. Charles H. Tompkins,
Washington, D. C.
Mr. John H. Towne,
New York, N. Y.
Mr. J. Barton Townsend,
Philadelphia, Pa.
Dr. Raynham Townshend,
New Haven, Conn.
Mr. Ernest B. Tracy,
New York, N. Y.
Dr. William Howard Treat,
Derby, Conn.
Mr. J. C. Trees,
Pittsburgh, Pa.
Gen. Harry C. Trexler,
Allentown, Pa.
Mr. George F. Trommer,
Brooklyn, N. Y.
Mr. Albert O. Trostel,
Milwaukee, Wis.
Mr. Calvin Truesdale,
New York, N. Y.
Mr. Regino Truffin,
Habana, Cuba.
Mr. Carll Tucker,
New York, N. Y.
Mr. Herbert G. Tully,
New York, N. Y.
Mr. George Tyson,
Boston, Mass.
Mr. Ernest Uehlinger,
New York, N. Y.
University of Buffalo,
Buffalo, N. Y.

(Presented by Mr. Jesse R. Porter, Mr. John C. Trefts, Mr. J. G. Jackson, Mr. R. B. Taylor, and Mr. August Keiser.)

Mr. Alvin Untermyer,
New York, N. Y.
Mr. George P. Urban,
Buffalo, N. Y.
Mr. George Urquhart,
New York, N. Y.
Mr. Ray A. Van Clief,
Buffalo, N. Y.
Mr. Frederick W. Vanderbilt,
New York, N. Y.
Mr. William H. Vanderbilt,
New York, N. Y.
Mrs. S. H. Vandergrift,
Washington, D. C.
Mr. H. A. Van Norman,
Los Angeles, Calif.,
Mr. John A. Vassilaros,
New York, N. Y.
Mr. S. M. Vauclain,
Philadelphia, Pa.
Mr. Albert L. Vits,
Manitowoc, Wis.
Mr. Ludwig Vogelstein,
New York, N. Y.
Mrs. James W. Wadsworth, jr.,
Washington, D. C.
Mr. George E. Waesche,
New York, N. Y.
Major Ennalls Waggaman,
Washington, D. C.
Mr. N. Erik Wahlberg,
Kenosha, Wis.
Mr. Sidney S. Walcott,
Buffalo, N. Y.
Mr. Elisha Walker,
New York, N. Y.
Mr. Harrington E. Walker (2 subscriptions),
Detroit, Mich.
Mr. Mahlon B. Wallace,
St. Louis, Mo.
Mr. Thomas J. Walsh,
New York, N. Y.
Mr. C. O. Wanvig,
Milwaukee, Wis.
Mrs. Herbert Ward,
London, England.
Mr. Bayard Warren,
Boston, Mass.
Mr. W. V. A. Waterman,
Albany, N. Y.
Mr. Horton Watkins,
St. Louis, Mo.
Mr. James S. Watson,
Rochester, N. Y.
Mr. Thomas John Watson,
New York, N. Y.
Dr. W. Lee Weadon,
Bridgeport, Conn.
Mr. Niel A. Weathers,
New York, N. Y.
Mr. George T. Webb,
New York, N. Y.
Mr. William X. Weed,
White Plains, N. Y.
Mr. J. Borton Weeks,
Chester, Pa.
Mrs. Laura R. Wells,
Washington, D. C.
Mr. George S. West,
Boston, Mass.
Mr. Richard Wetherill,
Chester, Pa.
Mr. F. O. Wetmore,
Chicago, Ill.
Mr. John W. Wheeler, jr.,
Bridgeport, Conn.
Mr. Albert C. Whitaker,
Wheeling, W. Va.
Mr. Harry C. Whitaker,
Wheeling, W. Va.
Mr. F. Edson White,
Chicago, Ill.
Col. Frank White,
Chattanooga, Tenn.
Mr. Lazarus White,
New York, N. Y.
Mr. Thomas W. White,
New York, N. Y.
Mr. Norman de R. Whitehouse,
New York, N. Y.
Mr. W. R. Whiteside,
Tulsa, Okla.
Mr. George A. Whiting,
Neenah, Wis.
Mr. George Whitney,
New York, N. Y.
Mr. Howard F. Whitney, jr.,
New York, N. Y.
Mr. Matthew P. Whittall,
Worcester, Mass.
Mr. Philip J. Wickser,
Buffalo, N. Y.

Mr. Edward Wigglesworth,
Boston, Mass.
Mr. Milo W. Wilder, jr.,
Newark, N. J.
Mr. Howard L. Wilkins,
Washington, D. C.
Mr. Blair S. Williams,
New York, N. Y.
Mr. Charles B. Williams,
New York, N. Y.
Mr. George M. Williams,
Indianapolis, Ind.
Mr. J. Ferrand Williams,
Detroit, Mich.
Mr. William H. Williams,
New York, N. Y.
Mr. Luther M. R. Willis,
Baltimore, Md.
Mr. Joseph Wilshire,
New York, N. Y.
Mr. John G. Wilshusen,
New York, N. Y.
Mr. James T. Wilson,
Kenosha, Wis.
Mr. John G. Winant,
Concord, N. H.
Mr. William E. Winchester,
New York, N. Y.
Mr. George A. Winsor,
New York, N. Y.
Mr. Benjamin Wood,
New York, N. Y.
Mr. Chalmers Wood,
New York, N. Y.
Mr. Howard O. Wood, jr.,
New York, N. Y.
Mr. Charles H. Woodhull,
Washington, D. C.
Dr. Frank A. Woods,
Holyoke, Mass.,
Mr. George C. Woolf,
New York, N. Y.
Mr. Clarence M. Woolley,
New York, N. Y.
Mr. Beverly Lyon Worden,
New York, N. Y.
Mr. George F. Wright,
Worcester, Mass.
Mr. Max Wulfsohn,
New York, N. Y.
Mr. Rudolph H. Wurlitzer,
Cincinnati, Ohio.
Mr. Thomas N. Wynne,
Indianapolis, Ind.
Mr. James Wyper,
Hartford, Conn.
Mr. Frederic L. Yeager,
New York, N. Y.
Mr. Fred W. Young,
Boston, Mass.
Mr. Christian B. Zabriskie,
New York, N. Y.
Mr. Robert P. Zobel,
New York, N. Y.

REPORT OF THE EXECUTIVE COMMITTEE OF THE BOARD OF REGENTS OF THE SMITHSONIAN INSTITUTION FOR THE YEAR ENDED JUNE 30, 1929

To the Board of Regents of the Smithsonian Institution:

Your executive committee respectfully submits the following report in relation to the funds of the Smithsonian Institution together with a statement of the appropriations by Congress for the Government bureaus in the administrative charge of the Institution.

SMITHSONIAN ENDOWMENT FUND

The original bequest of James Smithson was £104,960 8 shillings 6 pence—$508,318.46. Refunds of money expended in prosecution of the claim, freights, insurance, etc., together with payment into the fund of the sum of £5,015 which had been withheld during the lifetime of Madame de la Batut, brought the fund to the amount of	$550, 000. 00
Since the original bequest the Institution has received gifts from various sources, the income from which may be used for the general work of the Institution to the amount of	259, 184. 39
Total original endowments for general purposes	809, 184. 39
Capital gains from investment of savings from income	207, 796. 11
Capital gains from sales, stock dividends, etc	5, 405. 25
Present total of endowment for general purposes	1, 022, 385. 75

The Institution holds also a number of endowment gifts the income of each being restricted to specific use. These are invested and stand on the books of the Institution as follows:

Bacon, Virginia Purdy, fund, for a traveling scholarship to investigate fauna of countries other than the United States	$50, 000. 00
Baird, Lucy H., fund, for creating a memorial to Secretary Baird	1, 000. 00
Canfield collection fund, for increase and care of the Canfield collection of minerals	46, 232. 86
Casey, Thomas L., fund, for maintenance of Casey collection and promotion of researches relating to Coleoptera	3, 000. 00
Chamberlain, Frances Lea, fund, for increase and promotion of Isaac Lea collections of gems and mollusks	35, 000. 00
Hodgkins fund, specific, for increase and diffusion of more exact knowledge in regard to nature and properties of atmospheric air	100, 000. 00
Hughes, Bruce, fund, to found Hughes alcove	9, 021. 93

Myer, Catherine Walden, fund, for purchase of first-class works of art for the use of and benefit of the National Gallery of Art		$18, 267. 91
Pell, Cornelia Livingston, fund, for maintenance of Alfred Duane Pell collection		3, 000. 00
Poore, Lucy T. and George W., fund, for general use of the Institution when principal amounts to the sum of $250,000		24, 534. 92
Reid, Addison T., fund, for founding chair in biology in memory of Asher Tunis		9, 494. 50
Roebling fund, for care, improvement, and increase of Roebling collection of minerals		150, 000. 00
Springer, Frank, fund, for care, etc., of Springer collection and library		30, 000. 00
Walcott, Charles D., and Mary Vaux, research fund, for development of geological and paleontological studies and publishing results thereof		11, 520. 00
Younger, Helen Walcott, fund, held in trust		49, 812. 50
Total original endowments for specific purposes other than Freer endowment		540, 884. 62
Capital gains from investment of savings from income		65, 586. 11
Capital gains from stock dividends, sales, etc., of securities		19, 532. 97
Excluding Freer endowment, total present endowment for specific purposes		626, 003. 70
Freer Gallery of Art fund, for expenses of gallery (original endowment)	$1, 958, 591. 42	
Capital gains from investment of savings from income	398, 778. 71	
Capital gains from stock dividends, sales, etc., of securities	2, 878, 683. 89	
Total Freer endowment for specific purposes		5, 236, 054. 02
Total endowment for specific purposes		5, 862, 057. 72

SUMMARY

Invested endowment for general purposes	1, 022, 385. 75
Invested endowment for specific purposes other than Freer endowment	626, 003. 70
Total invested endowment other than Freer endowment	1, 648, 389. 45
Freer invested endowment for specific purposes	5, 236, 054. 02
Total invested endowment	6, 884, 443. 47

Classification of investments

Deposited in the United States Treasury at 6 per cent per annum, as authorized in United States Revised Statutes, section 5591		$1, 000, 000. 00
Invested in approved securities as follows:		
Investments other than Freer endowment—		
Bonds	$361, 901. 00	
Stocks	264, 988. 45	
Real estate first-mortgage notes	21, 500. 00	
		648, 389. 45
Total investments other than Freer endowment		1, 648, 389. 45

Invested in approved securities—Continued.

Investments of Freer endowment—		
Bonds	$2,785,000.34	
Stocks	2,360,553.68	
Real estate first-mortgage notes	90,500.00	
		$5,236,054.02
Total investments		6,884,443.47

Income from investments for present year

On $1,000,000 deposited in United States Treasury at 6 per cent	$60,000.00
On $648,389.45 invested in stocks and bonds other than Freer endowment at 4.71 per cent	30,582.77
Total income other than Freer endowment	90,582.77

FREER ENDOWMENT

On $5,236,054.02 invested in stocks, bonds, etc., at about 5.39 per cent	282,435.13
Total income from investments	373,017.90

Statement of the annual income of the Institution from all sources [1]

Cash balance on hand June 30, 1928		$238,369.41
Receipts:		
Cash from invested endowments and from miscellaneous sources for general use of the Institution	$61,309.56	
Cash for increase of endowments for specific use	3,000.00	
Cash for increase of endowments for general use	6,535.00	
Cash gifts for specific use (not to be invested)	50,111.01	
Cash received as royalties from sales of Smithsonian scientific series [2]	14,454.01	
Cash gain from sale, etc., of securities (to be invested)	22,944.95	
Cash income from endowments for specific use other than Freer endowment, and from miscellaneous sources	82,425.70	
Total receipts other than Freer endowment		240,780.23
Cash income from Freer endowment—		
Income from investments	282,435.13	
Gain from sale, etc., of securities (to be invested)	940,476.80	
		1,222,911.93
Total		1,702,061.57

[1] This statement does not include Government appropriations under the administrative charge of the Institution.

[2] Under resolution of the Board of Regents, three-fourths of this income is credited to the permanent endowment fund of the Institution and one-fourth is made expendable for general purposes.

82322—30——11

Disbursements:		
General work of the Institution—		
Buildings—care, repair, and alteration	$11,564.59	
Furniture and fixtures	746.06	
General administration [2]	20,652.66	
Library	3,006.55	
Publications (comprising preparation, printing, and distribution)	16,865.75	
Researches and explorations	13,707.11	
International exchanges	7,921.67	
		$74,464.39
Funds for specific use other than Freer endowment—		
Investments made from gifts, from gain from sales, etc., of securities, and from savings on income	51,860.45	
Other expenditures, consisting largely of research work, travel, increase and care of special collections, etc., from income of endowment funds and cash gifts for specific use	113,498.06	
		165,358.51
Freer endowment—		
Operating expenses of gallery, salaries, purchases of art objects, field expenses, etc	287,679.63	
Investments made from gain from sale, etc., of securities and from income	957,564.76	
		1,245,244.39
Balance June 30, 1929		216,994.28
Total		1,702,061.57

Expenditures for researches in pure science, explorations, care, increase, and study of collections, etc.

Expenditures from general endowment:		
Publications	$16,865.75	
Researches and explorations	13,707.11	
		$30,572.86
Expenditures from funds devoted to specific purposes:		
Researches and explorations, etc	$67,955.19	
Care, increase and study of special collections	18,078.97	
Publications	16,829.59	
Purchase of special library	3,500.00	
		106,363.75
Total		136,936.61

[2] This includes salaries of the secretary and certain others

Table showing growth of endowment funds of the Smithsonian Institution

Year	Endowment for general work of the Institution, being original Smithson bequest, gifts from other sources, and invested savings of income	Endowment for specific researches, etc., including invested savings of income	Freer gift for construction of Freer Gallery of Art Building	Freer bequest for operation of Freer Gallery of Art, including salaries, care, etc.
1846–1891	[1] $702,000.00			
1892	802,000.00	$101,000.00		
1893–94	852,000.00	101,000.00		
1895–1903	877,000.00	102,000.00		
1904–1913	885,807.58	111,692.42		
1914	885,807.58	116,692.42		
1915	886,084.02	143,515.98		
1916	887,607.08	160,527.30	$1,000,000.00	
1917	887,830.00	164,304.38		
1918	[2] 883,867.00	176,157.38		
1919	884,305.00	190,489.38		
1920	884,747.00	198,149.02		
1921	884,933.74	272,538.31	[3] 367,072.04	$1,253,004.75
1922	886,107.14	291,858.14		1,842,144.75
1923	886,246.14	306,524.14		[4] 3,296,574.75
1924	886,373.31	319,973.19		3,401,355.42
1925	886,769.73	338,136.77		3,459,705.34
1926	886,830.13	342,876.37		3,714,361.23
1927	886,877.79	498,401.96		4,171,880.61
1928	929,068.21	665,233.29		4,268,244.26
1929	[5] 1,022,385.75	626,003.70		5,236,054.02

[1] Original endowment plus income from savings during these years.
[2] Loss on account of bonds reduced on books from par to market value.
[3] Cash from sale of 2,000 shares of Parke, Davis & Co. stock, including dividends, and interest on gift of $1,000,000.
[4] In this year Parke, Davis & Co. declared 100 per cent stock dividend.
[5] Increase largely from funds transferred from specific endowment column and income released for genera work of the Institution.

BALANCE SHEET OF THE SMITHSONIAN INSTITUTION, JUNE 30, 1929

ASSETS

Stocks and bonds at acquirement value:		
Consolidated fund	$557,056.95	
Freer bequest	5,236,054.02	
Springer fund	30,000.00	
Walcott fund	11,520.00	
Younger fund	49,812.50	
		$5,884,443.47
U. S. Treasury deposit		1,000,000.00
Miscellaneous, principally funds advanced for printing publications and field expenses (to be repaid)		36,527.11
Cash:		
Funds in U. S. Treasury and in banks	$216,394.28	
On hand for petty transactions	600.00	
		216,994.28
Total		7,137,964.86

LIABILITIES

Freer bequest, capital accounts:		
Court and grounds fund	$574,524.12	
Court and grounds maintenance fund	148,112.53	
Curator fund	596,301.18	
Residuary estate fund	3,917,116.19	
		$5,236,054.02
Consolidated fund, capital accounts		557,056.95
Springer fund, capital		30,000.00
Walcott fund, capital		11,520.00
Younger fund, capital		49,812.50
U. S. Treasury deposit, capital		1,000,000.00
Freer bequest, current accounts:		
Court and grounds fund	58,042.28	
Court and grounds maintenance fund	10,311.88	
Curator	27,984.66	
Residuary estate fund	57,367.52	
		153,706.34
Springer fund, current account		849.93
Walcott fund, current account		1,365.00
Younger fund, current account		217.50
Miscellaneous cash accounts held by the Institution for the most part for specific use		97,382.62
Total		7,137,964.86

All payments are made by check, signed by the secretary of the Institution, on the Treasurer of the United States, and all revenues are deposited to the credit of the same account. In many instances deposits are placed in bank for convenience of collection and later are withdrawn in round amounts and deposited in the Treasury.

The practice of investing temporarily idle funds in time deposits has proven satisfactory. During the year the interest derived from this source, together with similar items, has resulted in a total of $5,631.82.

The foregoing report relates only to the private funds of the Smithsonian Institution. The following is a statement of the congressional appropriations for the past 10 years, for the support of the several governmental branches under the administrative control of the Institution and of appropriations for other special purposes during that period.

Table showing the appropriations made by Congress during the last 10 years, intrusted to the care of the Smithsonian Institution

Year	International Exchanges	American Ethnology	Cooperative ethnological researches	International Catalogue of Scientific Literature	Astrophysical Observatory	Increase of compensation	National Museum	Heating and equipping Aircraft Building
1920	$45,000.00	$42,000.00		$7,500.00	$13,000.00		$387,500.00	$14,000.00
1921	50,000.00	44,000.00		7,500.00	13,000.00		419,120.00	
1922	50,000.00	46,000.00		7,500.00	15,500.00		419,138.86	
1923	45,000.00	44,000.00		7,500.00	15,500.00	$109,044.00	418,120.00	
1924	43,000.00	44,000.00		7,500.00	15,500.00	112,704.00	415,000.00	
1925	49,550.00	57,160.00		8,861.66	21,580.00		547,292.00	
1926	46,260.00	57,160.00		8,000.00	[1] 31,180.00		554,392.00	
1927	46,260.00	57,160.00		7,500.00	31,180.00		565,820.00	
1928	46,855.00	58,720.00		7,260.00	32,060.00		606,960.00	
1929	48,208.00	60,300.00	$20,000.00	7,460.00	33,200.00		636,326.00	

Year	Safeguarding dome of Natural History Building	National Zoological Park	Additional for Zoological Park	National Gallery of Art	Printing and binding	Additional Assistant Secretary	Salaries and expenses	Additional fire protection
1920		$115,000.00						
1921		125,000.00	[2] $80,000.00	$15,000.00				
1922		125,000.00	[2] 2,500.00	15,000.00				
1923		125,000.00		15,000.00	$77,400.00			
1924		125,000.00		16,000.00	77,400.00			
1925		151,487.00		20,158.00	90,000.00	$6,000.00		$8,500.00
1926		157,000.00		21,028.00	90,000.00	6,000.00		
1927		173,199.00		29,381.00	90,000.00	6,000.00		
1928		175,000.00	[3] 25,000.00	30,356.00	90,000.00	[4] 7,500.00		
1929	[5] $80,000.00	182,050.00	[3] 30,000.00	31,168.00	95,000.00		$32,500.00	

[1] Increase in appropriation due to Government assuming part of the expenses of the Chilean station, which up to this time had been supported by private funds of the Smithsonian Institution.

[2] Additional land.

[3] Building for birds.

[4] After 1928 this item is included in appropriation for salaries and expenses.

[5] Work done by Supervising Architect and funds disbursed by United States Treasury.

The report of the audit of the Smithsonian private funds is printed below.

OCTOBER 2, 1929.

EXECUTIVE COMMITTEE, BOARD OF REGENTS,
Smithsonian Institution, Washington, D. C.

SIRS: We have examined the accounts and vouchers of the Smithsonian Institution for the fiscal year ended June 30, 1929, and certify the balance of cash on hand June 30, 1929, to be $216,994.28.

The vouchers representing payments from the Smithsonian income during the year, each of which bears the approval of the secretary or, in his absence, of the acting secretary, and a certificate that the materials and services charged were applied to the purposes of the Institution, have been examined in connection with the books of the Institution and agree with them.

Respectfully submitted.

CAPITAL AUDIT CO.,
WILLIAM L. YAEGER,
Certified Public Accountant.

Respectfully submitted.

FREDERIC A. DELANO,
R. WALTON MOORE,
J. C. MERRIAM,
Executive Committee.

PROCEEDINGS OF THE BOARD OF REGENTS OF THE SMITHSONIAN INSTITUTION FOR THE FISCAL YEAR ENDED JUNE 30, 1929

ANNUAL MEETING DECEMBER 13, 1928

Present: Chief Justice William H. Taft, chancellor, in the chair; Vice President Charles G. Dawes, Senator Joseph T. Robinson, Representative Albert Johnson, Representative R. Walton Moore, Representative Walter H. Newton, Mr. Frederic A. Delano, Hon. Irwin B. Laughlin, Hon. Dwight W. Morrow, Hon. Charles E. Hughes, Dr. John C. Merriam, and the secretary, Dr. C. G. Abbot. Dr. Alexander Wetmore, assistant secretary, was also present.

Mr. Delano offered the following resolution, which was adopted:

Resolved, That the income of the Institution for the fiscal year ending June 30, 1930, be appropriated for the service of the Institution, to be expended by the secretary, with the advice of the executive committee, with full discretion on the part of the secretary as to items.

The secretary presented his printed annual report, and then touched briefly upon a number of important matters that he considered worthy of the board's attention.

The annual report of the National Gallery of Art Commission was presented, and the following resolution was adopted:

Resolved, That the Board of Regents of the Smithsonian Institution hereby approves the recommendation of the National Gallery of Art Commission that Daniel Chester French, John E. Lodge, James Parmelee, and Edward W. Redfield be reelected as members of the commission for the ensuing term of four years, their present terms having expired.

Mr. Delano presented a statement regarding the lands occupied by the Institution and regarding its financial needs.

After a full discussion of the matter of an insecticide patent presented to the Institution, the board referred it to the permanent committee for consideration.

The Secretary announced the receipt of $3,500 from Mrs. E. H. Harriman, to be applied to the purchase of the William Healey Dall library for presentation to the Institution under the title "The Harriman Alaskan Library," and the following resolution was adopted:

Resolved, That the thanks of the Board of Regents of the Smithsonian Institution be conveyed to Mrs. E. H. Harriman for her generous gift of $3,500 for the purchase of the library of the late Dr. William Healey Dall and its presentation to the Institution under the title "The Harriman Alaskan Library."

MEETING OF FEBRUARY 14, 1929

Present: Chief Justice William H. Taft, chancellor, in the chair; Vice President Charles G. Dawes, Senator Reed Smoot, Senator Joseph T. Robinson, Senator Claude A. Swanson, Representative R. Walton Moore, Mr. Frederic A. Delano, Mr. Irwin B. Laughlin, and the secretary, Dr. C. G. Abbot. Dr. Alexander Wetmore, assistant secretary, was also present.

The Secretary announced that the President had approved the joint resolution of Congress reappointing Mr. Delano and Mr. Laughlin as citizen regents for the ensuing statutory term of six years from January 22, 1929.

The Secretary submitted a list of gifts made to the Institution since the last meeting.

Mr. Delano brought up the matter of the proposed contract transferring to the Research Corporation the promotion of the insecticide patent presented to the Institution. Under the terms of the contract, the Research Corporation assumes complete responsibility for the commercial development of the patent, the Institution receiving a fixed percentage of the returns as royalty. After a full discussion the board voted to approve the contract.

Assistant Secretary Wetmore presented a tentative program for necessary additional buildings for the Smithsonian Institution.

SPECIAL MEETING OF MAY 7, 1929

Present: Chief Justice William H. Taft, chancellor, in the chair; Senator Reed Smoot, Senator Joseph T. Robinson, Representative R. Walton Moore, Mr. Robert S. Brookings, Mr. Frederic A. Delano, Mr. Irwin B. Laughlin, Dr. John C. Merriam, and the secretary, Dr. C. G. Abbot. Dr. Alexander Wetmore, assistant secretary, was also present.

The secretary announced that on March 4 last Mr. Dawes automatically ceased to be a regent by the expiration of his term as Vice President, and that upon his inauguration, Vice President Charles Curtis became a regent ex officio. The secretary added that on April 26 the Vice President had appointed Senator Claude A. Swanson as a regent to succeed himself.

The secretary reported on the progress made in issuing the volumes of the Smithsonian Scientific Series, exhibiting copies of the first four volumes of the James Smithson Memorial Edition, and stating that the publishers were presenting a complete set of this edition to the Institution.

The secretary brought up the offer of the art collection of Mr. John Gellatly, which had been made through Mr. Gari Melchers, chairman of the National Gallery of Art Commission, and which had

been favorably considered both by the permanent committee and by the commission.

After discussion the following resolutions were adopted:

Resolved, That on the basis of the recommendation of the National Gallery of Art Commission expressed through the resolution adopted April 13, 1929, the Board of Regents of the Smithsonian Institution have examined the offer of Mr. John Gellatly relating to the proposed gift of his art collection as expressed in letters to Mr. Gari Melchers, chairman of the National Gallery of Art Commission, under dates of March 27 and March 30, 1929, and the board approves in principle the acceptance of this offer. The secretary is hereby requested to convey to Mr. Gellatly the sense of appreciation with which the board learns of this generous offer.

Resolved, That the board hereby refers the furtherance of the matter to the permanent committee with full power to act.

Senator Robinson, on behalf of the legal committee on the Freer will and gift, submitted its report on the interpretation of the terms of the Freer will.

GENERAL APPENDIX

TO THE

SMITHSONIAN REPORT FOR 1929

ADVERTISEMENT

The object of the General Appendix to the Annual Report of the Smithsonian Institution is to furnish brief accounts of scientific discovery in particular directions; reports of investigations made by collaborators of the Institution; and memoirs of a general character or on special topics that are of interest or value to the numerous correspondents of the Institution.

It has been a prominent object of the Board of Regents of the Smithsonian Institution from a very early date to enrich the annual report required of them by law with memoirs illustrating the more remarkable and important developments in physical and biological discovery, as well as showing the general character of the operations of the Institution; and, during the greater part of its history, this purpose has been carried out largely by the publication of such papers as would possess an interest to all attracted by scientific progress.

In 1880, induced in part by the discontinuance of an annual summary of progress which for 30 years previously had been issued by well-known private publishing firms, the secretary had a series of abstracts prepared by competent collaborators, showing concisely the prominent features of recent scientific progress in astronomy, geology, meteorology, physics, chemistry, mineralogy, botany, zoology, and anthropology. This latter plan was continued, though not altogether satisfactorily, down to and including the year 1888.

In the report for 1889 a return was made to the earlier method of presenting a miscellaneous selection of papers (some of them original) embracing a considerable range of scientific investigation and discussion. This method has been continued in the present report for 1929.

THE PHYSICS OF THE UNIVERSE [1]

By Sir JAMES JEANS, Sec. R. S.

The ancients were for the most part content to regard the universe as a theatre which had been specially constructed for the drama of human life. Men, and even the gods that man had created in his own image, came, lived, and disappeared after strutting their tiny hour upon a stage to which the eternal hills and the unchanging heavens formed a permanent background. While some thought was given to the birth of the universe, and its creation or emergence from chaos, very few thought of it as living its life and passing from birth to death in the same way as a man or a tree passes from birth to death.

In modern times the idea of secular change crept into the picture. Geologists began to study the earth as a changing structure, and astronomers to give thought to the evolution of the stars, recognizing them as bodies which are born, live their lives of gradual change, and finally die. But the ultimate constituents of the universe, the atoms, were still supposed to be immune from change. The hypothesis that all matter consisted of permanent, indivisible, and unchangeable atoms, which had been advanced so far back as the fifth century B. C. by Leucippus and Democritus, remained practically unshaken until the end of the nineteenth century. The ageing of the universe was supposed to amount to nothing more than a rearrangement of indestructible units which were themselves incapable of any sort of change or decay. Like a child's box of wooden bricks, the atoms made many buildings in turn.

ATOMIC CHANGES

Then Crookes, Lenard, and, above all, Sir J. J. Thomson, began to break up the atom. The bricks of the universe which had been deemed unbreakable for more than 2,000 years were suddenly shown to be very susceptible to having fragments chipped off; a milestone was reached in 1895, when Sir. J. J. Thomson showed that these

[1] The first Henry Herbert Wills Memorial Lecture of the University of Bristol, delivered at the University on Oct. 30. Reprinted by permission from Supplement to Nature, Nov. 3, 1928.

fragments were identical, no matter what type of atom they came from; they were of equal mass, and they carried equal negative charges of electricity, and so were called electrons. Two years later, Lorentz's explanation of the newly discovered Zeeman effect provided evidence that the moving parts in atomic interiors were precisely similar electrons.

The series of researches so initiated were, after a few years, coordinated in the Rutherford view of atomic structure, which supposed the chemical properties and nature of the atom to reside in an excessively minute central nucleus carrying a positive charge of electricity, about which the negatively charged electrons described wide orbits. By clearing a space around the central nucleus, and so preventing other atoms from coming too near, these electronic orbits gave size to the atom. The volume of space kept clear by the electrons is enormously greater than the total volume of the electrons; roughly, the ratio of volumes is that of the battlefield to the bullets. The atom, with a radius of about 2×10^{-8} cm., has about 100,000 times the dimensions, and so about 10^{15} times the volume, of a single electron, of which the radius is about 2×10^{-13} cm. In all probability the nucleus is even smaller than the electrons. The number of orbital electrons in an atom is called the atomic number of the atom; it ranges from unity in hydrogen, the lightest and simplest of atoms, to 92 in uranium, which is the most massive and complex atom known.

Simultaneously with this, physical science was discovering that the nuclei themselves were neither permanent nor indestructible. In 1896, Becquerel had found that uranium salts had the remarkable property, as it then appeared, of spontaneously affecting photographic plates in their vicinity. This observation led to the discovery of a new property of matter, namely, radioactivity, and all the results obtained in the next few years were coordinated in the hypothesis of spontaneous disintegration advanced by Rutherford and Soddy in 1903, according to which radioactivity indicates a spontaneous break-up of the atomic nuclei. So far from the atoms being permanent and indestructible, their very nuclei were now seen to crumble away with the mere lapse of time, so that what was once the nucleus of a uranium atom was transformed, after sufficient time, into the nucleus of a lead atom, and eight α-particles, which are the nuclei of helium atoms. Radiation is given off in the process, the radiation that affected Becquerel's photographic plates, and so led to the detection of the radioactive property of matter.

With the unimportant exceptions of potassium and rubidium, the property of radioactivity occurs only in the most complex and massive of atoms, being indeed limited to those of atomic numbers above 83. Yet, although the lighter atoms are not liable to spontaneous

disintegration in the same way as the heavy radioactive atoms, the nuclei of these also are of composite structure, and can be broken up by artificial means. In 1920, Rutherford succeeded in breaking up the nuclei of atoms of oxygen and nitrogen by bombarding them with swiftly moving α-particles.

The success of this experiment led to the hypothesis, which has not yet been established beyond all possibility of doubt, that the whole universe is built up of only two kinds of ultimate bricks, namely, electrons and protons. Each proton carries a positive charge which is exactly equal in amount to the negative charge carried by an electron. The protons are supposed to be identical with the nucleus of the hydrogen atom; all other nuclei are supposed to consist of closely packed structures of protons and electrons.

In addition to containing material electrons and protons, the atom contains yet a third ingredient, namely, electromagnetic energy. Modern electromagnetic theory shows that all radiation carries mass about with it, one gram of mass being associated with 9×10^{20} ergs or 2.15×10^{13} calories of radiation. As a necessary consequence, any substance which is emitting radiation must also be losing mass; the spontaneous disintegration of any radioactive substance involves a spontaneous decrease of weight. The ultimate fate of a gram of uranium may be expressed by the equation:

$$1 \text{ gram uranium} = \begin{cases} 0.8653 \text{ gm. lead.} \\ 0.1345 \text{ gm. helium.} \\ 0.0002 \text{ gm. radiation.} \end{cases}$$

Stated in a very general form, the phenomenon of radioactivity may be described as a transformation of material mass into radiation or, to put it slightly differently, as the liberation of radiation by the destruction of material mass. Where 4,000 gm. of matter originally existed, only 3,999 gm. now remain, the remaining gram having gone off in the form of radiation.

Yet, the 3,999 gm. of lead and helium contain precisely the same protons and electrons as the original 4,000 gm. of uranium; we may then say that the 4,000 gm. of uranium consisted of these electrons and protons together with 1 gm. of bottled-up electromagnetic energy which has since escaped in the form of radiation.

So far as terrestrial experience goes, this dissolution of mass into radiation is entirely a one-way process. Terrestrial rocks provide abundant evidence of uranium having continuously broken up into lead, helium, and radiation for the past thousand million years or more, but there is no evidence of the converse process ever having occurred. We must suppose that there is less uranium on earth to-day than there was yesterday, and that by to-morrow there will be still less. As a consequence, the earth each day radiates away a little more heat than

it receives from the sun, and its mass continually diminishes. According to Jeffreys [2] the outward flow of radiation just inside the earth's surface is about 1.9×10^{-6} calorie per sq. cm. per second, all but about 13 per cent of which arises from radioactive disintegration of the substance of the earth. We can calculate from this that radioactive disintegration causes the earth's mass to diminish at the rate of rather less than an ounce a minute; at this rate, terrestrial atoms are unbottling their energy and pouring it into space in the form of radiation. On earth at least the stream flows ever in the same direction; complex atoms giving place to simple, and mass changing into radiation. It is natural to ask whether a study of the physics of the universe reveals these processes as part only of a closed cycle, so that the wastage which we see in progress on earth is made good elsewhere. We stand on the banks of a river and watch its current ever carrying water out to sea, but we know that this water is in due course transformed into clouds and rain which replenish the river. Is the physical universe a similar cyclic system, or ought we rather to compare it to a stream which, having no source of replenishment, must cease flowing after it has spent itself? To answer these questions we must attempt first to trace our terrestrial stream back to its source.

THE ORIGIN OF TERRESTRIAL RADIUM AND URANIUM

Radioactive atoms are of many kinds, but all have in common the property of spontaneous disintegration. The period of time required for this disintegration to occur varies enormously, some types of atoms having long lives of thousands of millions of years, while others have short lives of years, days, hours, or seconds, the most ephemeral of all being actinium-A, with an average life of only 0.002 second. Let us take uranium and radium as being typical of the two classes.

Spontaneous disintegration reduces any store of radium to half in 1,580 years, so that if a whole earth were built of pure radium only a single atom would be left after a quarter of a million years. Since the earth is many millions of years old, we may be confident that every atom of radium now on earth was born on earth. Soddy, Boltwood, and others have investigated the ancestry of radium. Its direct parent is found to be ionium, and it traces its descent back through uranium-X to uranium itself.

On the other hand, it takes 5,000,000,000 years for a store of uranium to diminish to half. As the earth was born out of the sun some 2,000,000,000 years ago, the greater part of any uranium it may have brought with it out of the sun would still be in existence. As we have no evidence of any uranium being born on earth, and as no parent substance is known out of which uranium could be born, it is reason-

[2] "The Earth," p. 83.

able to regard the earth's present store of uranium as the remains of a supply it originally brought out of the sun. An initial store of about 10^{19} gm. would suffice.

This uranium can not have existed from all time for the average life of a uranium atom is only about 7,000,000,000 years. How, then, did it come into being? Was it created in the sun, or did the sun, like the earth, start life with a supply which has continually diminished, and is destined ultimately to vanish entirely?

The answer to this question must of course depend on the age we assign to the sun, and an attempt to fix this takes us rather far afield.

THE AGES OF THE SUN AND STARS

In a classical paper published in 1878, Clerk Maxwell studied the behavior of a gas whose molecules were supposed to be massive points repelling one another with a force which varied inversely as the fifth power of the distance. There was no possibility of direct collision, since the molecules were supposed to be of infinitesimal size, but as each molecule threaded its way through its fellows, pairs occasionally approached so close as to influence one another's motion much as a direct collision would have done. At each such encounter a transfer of energy took place, the general tendency being towards equalizing energies: the molecule with the greater energy of motion was ever being slowed down, and that with the lesser energy speeded up. If the molecules were of different weights, their continued encounters tended to bring about a state in which heavy and light molecules all moved with the same energy, the lighter molecules making up for the smallness of their mass by the rapidity of their motion.

It was no new discovery that the molecules of a gas tended to assume such a state. This had been known for some years, but Maxwell's investigation gave a means of calculating the time required to bring about this final state of equipartition of energy. Maxwell calculated a time, which he called the time of relaxation, such that all deviations from the final state of equipartition of energy were reduced to $1/e$ (37 per cent) of their original value in this time. For ordinary air it is found to be about $\frac{1}{6\times 10^9}$ second.

Maxwell's massive points, repelling according to the inverse fifth power of the distance, do not form a particularly good model of a gas, but on changing the law of a force to an attraction varying as the inverse square of the distance (the law of gravitation), we obtain an absolutely realistic model of the stars, the diameter of the stars being so small in comparison with their mean distances apart that the possibility of direct collisions may be ignored entirely. Just as Maxwell calculated the time of relaxation for his ideal gas, we can calculate it

for a collection of massive points, having the masses and mean distances of the stars and attracting according to the law of gravitation. It proves to be of the order of millions of millions of years. After interacting on one another for a certain number, then, of millions of millions of years, the stars must attain to a final state of equipartition of energy in which the average energy of all types of stars is the same, regardless of their mass.

So far back as 1911, Halm had suspected an approximation to equality in the energies of massive and light stars, and suggested that the velocities of the stars, like those of the molecules of a gas, might conform to the law of equipartition of energy. A more exhaustive investigation by Seares in 1922 showed the supposed approximation to be real. Table I shows the average total velocity (C) obtained for stars of different types having different mean masses.

Everywhere, except in its first two lines, the table reveals a marked approximation to equality of energy of motion. The last 10 lines show a range of 10 to 1 in mass, but the average deviation of energy from the mean is only 9 per cent. This equality of energy can only be attributed to the gravitational interaction of the stars. For if it were produced by any physical agency, such as pressure of radiation, bombardment by molecules, atoms or high-speed electrons, this agency, as the last column of the table shows, would have to be in thermodynamical equilibrium with matter at a temperature of the order of 2×10^{62} degrees. Since no such temperatures are known in nature, we must conclude that the observed equality of energy is the result of gravitational interactions extending over millions of millions of years. The stars must, then, have an age of this order of magnitude.

Other lines of astronomical investigation lead to the same conclusion; I will limit myself to one. A number of stars are "binary," consisting of two distinct masses which travel through space in double harness, describing closed orbits about one another because neither can escape from the gravitational hold of its companion. The single stars we have just discussed may appropriately be compared to monatomic molecules, but these binary stars must be compared to diatomic molecules. Energy can reside in their orbital motion as well as in their motion through space. Again we find that endless gravitational encounters must result in equipartition of energy, both from star to star and also between the different motions of which each binary system is capable. Further, when this final state is reached, the eccentricities of the elliptic orbits must be distributed over all values from $e=0$ to $e=1$ in such a way that all values of e^2 are equally probable.

TABLE I.—*Equipartition of energy in stellar motions*

Type of star	Mean mass, M	Mean velocity, C	Mean energy $\frac{1}{2}MC^2$	Corresponding temperature
Spectral type:				°
*B*3	19.8×10^{33}	14.8×10^{5}	1.95×10^{46}	1.0×10^{62}
*B*8.5	12.9	15.8	1.62	0.8
*A*0	12.1	24.5	3.63	1.8
*A*2	10.0	27.2	3.72	1.8
*A*5	8.0	29.9	3.55	1.7
*F*0	5.0	35.9	3.24	1.6
*F*5	3.1	47.9	3.55	1.7
*G*0	2.0	64.6	4.07	2.0
*G*5	1.5	77.6	4.57	2.2
*K*0	1.4	79.4	4.27	2.1
*K*5	1.2	74.1	3.39	1.7
*M*0	1.2	77.6	3.55	1.7

This final law of distribution of eccentricity of orbit is independent of the size of the orbit, but the time of relaxation which measures the rate of approach to this final state is not. For the eccentricity of orbit is a differential effect, arising from the difference of the gravitational pulls of a passing star on the two components of the binary, and when these components are close together the passing star can get no grip on the orbit. For visual binaries, in which the components are usually hundreds of millions of miles apart, the "time of relaxation" is again millions of millions of years, but it is a hundred times as great as this for the far more compact spectroscopic binaries.

The following table, compiled from material given by Aitken, shows the observed distribution of eccentricities:

TABLE II.—*The approach to equipartition of energy in binary orbits*

Eccentricity of orbit	Observed number of spectroscopic binaries	Observed number of visual binaries	Number in final state
0 to 0.2	78	7	6
0.2 to 0.4	18	18	18
0.4 to 0.6	16	28	30
0.6 to 0.8	6	11	42
0.8 to 1.0	1	4	54

As we should anticipate, the spectroscopic binaries show no approach to the final state; most of them retain the low eccentricity of orbit with which they start life. The visual binaries show a good approach up to an eccentricity of about 0.6, but not beyond. The deficiency of orbits of high eccentricity may mean that gravitational forces have not had sufficient time to produce the highest eccentricities of all, but part, and perhaps all, of the deficiency must be ascribed to the observational difficulty of detecting orbits of high eccentricity.

Clearly, however, the study both of orbital motions and of motions through space points to gravitational action extending over millions

of millions of years. In each case there is an exception to "prove the rule". In the former case, it is provided by the spectroscopic binaries which are so compact that their constituents can defy the pulling-apart action of gravitation; in the latter case it is provided by the *B*-type stars which are so massive, possibly also so young, that the gravitational forces from lesser stars have not greatly affected their motion.

This and other lines of evidence, when discussed in detail, agree in suggesting that the general age of the stars is probably between five and ten million million years. It may even be possible to fix the age of the sun within the narrower limits of seven and eight million million years.

THE ORIGIN OF SOLAR URANIUM

We now have all the data for discussing the origin of the radioactive atoms in the sun and stars. Thorium, the longest-lived of all radioactive substances, is reduced to half its original amount after 15,000,000,000 years of spontaneous disintegration. A mass of pure thorium equal to the sun (2×10^{33} gm.) would be reduced to a single atom within three million million years. For uranium, with a half-value period of 5,000,000,000 years, the corresponding time is less than a million million years. When the earth was born the sun's age was greater than either of these times, so that the earth's portion of radioactive matter must have been generated during the sun's life in the sun itself.

The only possible escape from this conclusion would seem to lie in the supposition that the lives of atoms of uranium and thorium are in some way enormously prolonged by intense heat and fierce bombardment such as occur in the sun's interior. We can not absolutely rule such a possibility out, but it is difficult to see any single consideration which could be adduced in its favor from the side either of experimental or of theoretical physics, and, in the present state of our knowledge, it would seem reasonable to disregard it.

Assuming that these atoms were born in the sun, the problem of the manner of their birth takes us to the very heart of present-day theoretical physics.

Let us consider, in some detail, two processes which occur on earth: The change of atomic make-up through a readjustment of electrons, and the change of nuclear make-up through spontaneous disintegration.

At first sight the two processes seem very dissimilar. The radioactive transformation of the nucleus is spontaneous, in the sense that nothing that we can do either expedites or hinders it. Each atom of uranium carries its own future history written inside it. It

lives its appointed life serenely undisturbed by external accidents of heat or pressure; when its hour strikes it will cease to exist as uranium and will proceed to disintegrate into lead, helium, and radiation. Its nucleus slips back to a state of lower energy, the lost energy being put in evidence as emitted radiation. On the other hand the change produced in ordinary atoms by electronic rearrangement is extremely susceptible to external physical conditions. Every spectroscopist knows how to chip off one, two, or even three electrons from the atom at will. Nevertheless, as was first made clear in a remarkable paper which Einstein published in 1917,[3] the difference is merely one of degree and not of kind.

The electrons in an atom are free to move from one orbit to another, and as the various possible orbits have different energies, the atom constitutes, to some extent, a reservoir of energy. For example, the hydrogen atom consists of a single proton as central nucleus, and a single electron revolving round it. According to Bohr's theory, the electron can revolve in orbits whose diameters (or major axes) are proportional to the squares of the natural numbers, 1, 4, 9, 16, 25, . . . The differences of energy between the various orbits are easily calculated; for example, the smallest two orbits differ in energy by 16×10^{-12} erg. If we add 16×10^{-12} erg of energy to an atom in which the electron is describing the smallest orbit of all, it crosses over to the next orbit, absorbing the 16×10^{-12} erg in the process and so becoming temporarily a reservoir of energy holding 16×10^{-12} erg. If the atom is disturbed, it may of course discharge the energy at any time, or it may absorb still more energy and so increase its store. But if it is left entirely undisturbed, the electron must, after a certain time, lapse back spontaneously to its original smaller orbit. If it were not so, Planck's well-established law of black-body radiation could not be true. In this process the atom ejects 16×10^{-12} erg of energy in the form of radiation and, as a consequence, experiences a diminution of mass to the extent of 1.8×10^{-32} gm. Thus a collection of hydrogen atoms in which the electrons describe orbits larger than the smallest possible is similar to a collection of uranium atoms in that the atoms spontaneously lapse back to their states of lower energy as a result merely of the passage of time, losing mass and emitting radiation in the process.

We have spoken of adding 16×10^{-12} erg of energy to a hydrogen atom in its state of lowest energy. We can not of course do this simply by pouring miscellaneous energy on the atom, and expecting it to drink it up. The hydrogen atom only accepts energy which is offered it in the form of radiation of precisely the right wave length; it treats all other radiation with complete indifference. Every atom

[3] Phys. Zeitsch., vol. 48, p. 122, 1917.

is selective in the sense in which a penny-in-the-slot machine is selective; if we pour radiation of the wrong frequency on to an atom we may reproduce the comedy of the millionaire whose total wealth will not procure him a box of matches because he has not a loose penny, or we may reproduce the tragedy of the child who can not obtain a slab of chocolate because its hoarded wealth consists of farthings and halfpence, but we shall not disturb the hydrogen atom.

This selective action of the atom on radiation is put in evidence in a variety of ways, but is perhaps most simply shown in the spectra of the stars. Light of all wave lengths streams out from the hot interior of a star and bombards the atoms which form its atmosphere. These atoms drink up that radiation which is of precisely the right wave length, but have no interaction of any kind with the rest, with the result that the radiation which is finally emitted from the star is deficient in just these particular wave lengths. This is shown by the star showing an *absorption spectrum* of fine lines. As the atoms in the star's atmosphere absorb this radiation they move to orbits of higher energy, but in course of time they lapse back to their old orbits, and in doing so emit energy in the form of radiation of precisely these same wave lengths. This does not, as might at first be thought, exactly neutralize the absorption of radiation, because the absorbed radiation was all traveling outwards, whereas the emitted radiation travels in all directions at random. Thus, if we view the atmosphere tangentially, as we can do with the sun's atmosphere at a total eclipse, we observe the same spectrum, no longer as an absorption but as an *emission spectrum;* it no longer consists of dark, but of bright lines—the "flash" spectrum.

Any atom, or indeed any other electrical structure, will select the radiation of suitable wave length from all the radiation which falls on it, and use the energy of this radiation in rearranging its electron orbits. The amount of energy ϵ that the atom absorbs is connected with the wave length λ of the radiation by the quantum relation $\epsilon\lambda = hC$, where h is Planck's constant (6.55×10^{-27} erg sec.), and C is the velocity of light. The quantity ϵ of energy given by this relation is called the "quantum" of light of wave length λ, and the wave lengths of the radiation which any electrical structure selects are determined by the condition that the corresponding quantum of energy shall just suffice to shift its electrons from one orbit to another. Radiation will also be absorbed if its quantum provide sufficient energy to tear the electron out of the atom altogether, and set it traveling through space as a free electron. All radiation of which the wave length is less than a certain critical limit fulfils this latter condition.

The more compact an electrical structure is, the greater the energy necessary to disturb it; and the greater the quantum of energy ϵ,

the shorter the wave length of the corresponding radiation. It follows that a very compact structure can only be disturbed by radiation of very short wave length.

As a rough working guide we may say that any structure will only be disturbed by radiation whose wave length is less than 860 times the dimensions of the structure. The energy needed to separate two electric charges $+e$ and $-e$, at a distance r apart, is e^2/r, and, in general, the energy needed to rearrange or break up a structure of electrons and protons of linear dimensions r will be comparable with this. If λ is the wave length of the requisite radiation, the energy made available by the absorption of this radiation is the quantum hC/λ. Combining this with the circumstance that the value of h is very approximately 860 e^2/C, we find that the requisite wave length of radiation is about 860 times the dimensions of the structure to be broken up. In brief, the reason why blue light affects photographic plates, while red light does not, is that the wave length of blue light is less, and that of red light is greater, than 860 times the diameter of the molecule of silver nitrate; we must get below the 860-limit before anything begins to happen.

The wave length of the light emitted by an atom when it discharges its reservoir of energy is precisely the same as that of the light absorbed when it originally stored up this energy, for as the two quanta of energy are the same, the corresponding wave lengths are the same. It follows that the light emitted by any electrical structure will have a wave length of about 860 times the dimensions of the structure. For example, ordinary visible light has a wave length equal to about 860 atomic diameters.

Atomic nuclei, like the atoms themselves, are structures of positive and negative electrical charges, and so ought to behave similarly with respect to the radiation falling upon them. The radiation which the atomic nuclei emit, and consequently also that which they are prepared to absorb, is, however, of far shorter wave length than that emitted or absorbed by complete atoms. Ellis and others have found, for example, that the radiation which is emitted during the disintegration of radium-B has wave lengths of 3.52, 4.20, 4.80, 5.13, and 23×10^{-10} cm. These wave lengths are only about a hundred-thousandth part of those of visible light. The reason is, of course, that the nucleus has only about a hundred-thousandth part the dimensions of the atom.

Since the wave length of the radiation absorbed or emitted by an atom is inversely proportional to the quantum of energy, it follows that the quantum of energy needed to work the atomic nucleus is about 100,000 times as great as that needed to work the atom. If

we compare the hydrogen atom to a penny-in-the-slot machine, nothing less than 500-pound notes will work the radioactive nuclei.

Yet radiation of the wave lengths just mentioned ought to be just as effective in rearranging the nucleus of radium-*B* as that of the longer wave length is effective in rearranging the hydrogen atom. At least such radiation ought to precipitate the disintegration of radium-*B*. Whether it could ever be effective in forming radium-*B* out of radium-*C* and atoms of helium (or α- and β-particles) is a somewhat different question; possibly other conditions of which nothing is known must be fulfilled in addition to the presence of radiation of the appropriate wave length.

Probably also the radioactive nuclei, like those of nitrogen and oxygen, could be broken up by a sufficiently intense bombardment, although the experimental evidence on this point is not very definite. If so, each bombarding particle would have to bring to the attack energy equal at least to that of one quantum of the radiation in question, and this requires it to move with an enormously high velocity.

In passing, we may notice that processes of the general type we have just been discussing form the hope of those modern alchemists who aspire to obtain gold by the transmutation of other metals. In its widest form, their ambition is to combine the electrons and protons of base metals with the third atomic ingredient, namely, electromagnetic energy, so as to form atoms of gold. Any success they may achieve will probably result in a gain of knowledge to abstract science rather than of wealth to themselves, since one of the ingredients they must necessarily use, namely, energy or radiation, is so expensive as to render the final product excessively costly. It would need at least an appreciable fraction of an ounce of energy to produce an ounce of gold, and with electric power at even a farthing per unit, energy and radiation cost 11,000,000 pounds per ounce. Whatever the gold standard may have to fear on the political side, it would appear to be thoroughly impregnable on the side of physics and chemistry.

Every wave length of radiation has a definite temperature associated with it, namely, the temperature at which radiation of this particular wave length is most abundant. We recognize this when we speak of a red heat or a white heat, and, although we do not do so, we might quite legitimately speak in the same way of an ultra-violet heat or an X-ray heat. The wave length and the associated temperature are connected through the well-known relation:

$$\lambda T = 0.2885 \text{ cm. degree}$$

When this particular temperature begins to be approached, but not before, radiation of the wave length in question becomes abundant; at temperatures well below this it is quite inappreciable.

We have seen that radiation of short wave length is needed to break up an electric structure of small dimensions, and as we now see that short wave lengths are associated with high temperatures, it appears that the smaller a structure is, the greater the heat needed to break it up. On combining the relation just given between T and λ with that implied in the rough law of the "860 limit," it appears that a structure of dimensions r cm. will begin to be broken up by temperature radiation when the temperature first approaches $1/3000r$. Atoms, for example, whose general dimensions are of the order of 10^{-8} cm., begin to be broken up when the temperature approaches 30,000°; nuclei, whose general dimensions are of the order of 10^{-13} cm., must remain unaffected until the temperature approaches 3,000,000,000°.

To take a more precise instance, yellow light of wave length 6000A is specially associated with the temperature 4,800°. At temperatures well below this there is no yellow light except such as is artificially created. Stars, and all other bodies, at a temperature of about 4,800°, are of a yellowish color and show lines in the yellow region of their spectrum. These lines occur because yellow light removes the outermost electron from the atoms of calcium and similar elements. When a temperature of 4,800° begins to be approached, but not before, rearrangements of the electrons in the calcium atom begin to occur. This temperature is not approached on earth (except in the electric arc and other artificial conditions) so that terrestrial calcium atoms in general are at rest in their states of lowest energy. Einstein's paper of 1917 showed it to be a necessary deduction from Planck's law of black-body radiation that a collection of calcium atoms in other states would behave precisely like atoms of radioactive substances to the extent of spontaneously slipping back to states of lower energy.

Just as calcium atoms in the cool temperatures of the earth simulate the behavior of radioactive atoms, so radioactive nuclei, if raised to a sufficiently high temperature, would simulate the behavior of calcium atoms in the hot atmosphere of a star. The shortest wave length of radiation emitted in the transformation of uranium is about 0.5×10^{-10} cm., and this corresponds to a temperature of 5,800,000,000°. When some such temperature begins to be approached, but not before, the constituents of the radioactive nuclei begin to rearrange themselves just as the constituents of the calcium atom do when a temperature of 4,800° is approached.

We must probably suppose that rearrangements can also be effected by bombarding the electric structure with material particles. If so,

the temperature at which bombardment by electrons, nuclei, or molecules would first begin to be effective is precisely the same as that at which radiation of the effective wave length would first begin to be appreciable; the two processes begin at the same temperature.

TABLE III.—*The mechanical effects of radiation*

Wave lengths (cm.)	Nature of radiation	Effect on atom	Temperature (degrees abs.)	Where found
$7,500\times10^{-8}$ to $3,750\times10^{-8}$	Visible light	Disturbs outermost electrons.	3,850 to 7,700	Stellar atmospheres.
250×10^{-8} to 10^{-8}	X rays	Disturbs inner electrons.	115,000 to 29,000,000	Stellar interiors.
5×10^{-9} to 10^{-9}	Soft γ rays	Strip off all or nearly all electrons.	58,000,000 to 290,000,000	Central regions of dense stars. (?).
4×10^{-10}	γ rays of radium-*B*.	Disturbs nuclear arrangement.	720,000,000	
5×10^{-11}	Hardest γ rays.	----------	5,800,000,000	
4.5×10^{-12}	(?)	Building of helium atom out of hydrogen.	64,000,000,000	
2×10^{-12} [1]	Highly-penetrating radiation.	Disintegrates nuclei.	150,000,000,000	
1.3×10^{-13}	(?)	Annihilation or creation of proton and accompanying electron.	2,200,000,000,000	

[1] See added item on p. 179.

We have seen, then, that the apparent difference between the behavior of the calcium atom and of the uranium nucleus reduces, in theory, to a mere difference of temperature, although in practice the difference is all the difference between 5,000° and 5,000,000,000°. The lower temperature is approached or exceeded in the atmospheres of most stars, so that the calcium atom is continually rearranging itself in these atmospheres, as is shown by the presence of the *H* and *K* lines of calcium in most stellar spectra. It is unlikely that the higher temperature is approached anywhere in the universe, although exceptions, arising from our ignorance rather than our knowledge, must possibly be made in favor of the centers of certain "white-dwarf" stars and of the spiral nebulæ. Apart from these, no place is known hot enough to have any appreciable effect on the transformation, either by synthesis or by disintegration, of the radioactive elements, and we must conclude that they behave everywhere in the same spontaneous fatalistic way that they do on earth; nowhere is there sufficiently intense heat to cause them to vary their conduct.

Thus solar uranium, which, as we have already seen, must have been born in the sun, can scarcely have been born out of the synthesis of lighter elements, and so must have originated out of the disintegration of heavier elements. The position with respect to solar uranium is precisely analogous to that we have already reached in respect of terrestrial radium, but there is the outstanding difference that we

know the ancestry of terrestrial radium, whereas we do not know that of solar uranium. But ancestry there must be, so that we are led directly to the conjecture that the sun must have contained, and presumably must still contain, atoms of atomic weight greater than that of uranium; astronomical evidence leads independently to the same conclusion. We are led to contemplate terrestrial uranium merely as the present generation of an ancestry that extends we know not how far back. The complete series of chemical elements contains elements of greater atomic weight than uranium, but all such have, to the best of our knowledge, vanished from the earth, as uranium also is destined to do in time.

Table III above shows the wave lengths of the radiation necessary to effect various atomic transformations. The last two columns show the corresponding temperatures, and the places, so far as we know, where this temperature is to be found. In places where the temperature is far below that mentioned in the last column but one, the transformation in question can not be affected by heat, and so can only occur spontaneously. Thus it is entirely a one-way process. The available radiation is not of the right wave length to work the atomic slot machine, so that the atoms, absorbing no energy from the surrounding radiation, are continually slipping back into states of lower energy, if such exist; they continually transform their mass into radiation, while the converse transformation of radiation into mass can not occur.

For the sake of completeness, the table has been extended so as to include certain other phenomena, not so far discussed, to which we now turn.

THE ANNIHILATION OF MATTER

Every square centimeter of the sun's surface discharges radiation out into space at the rate of about 1,500 calories a second, from which we can calculate that the sun's total mass is diminishing at about 250,000,000 tons a minute. Whereas the flow of mass from the earth's surface, a total loss of about an ounce a minute, is about equal to the flow of water from a dripping tap, the flow of mass from the sun's surface is about 650 times the flow of water over Niagara. Many stars lose mass even more rapidly; S. Doradus loses mass at the rate of about 200,000,000 Niagaras. The earth's loss of mass is readily explained in terms of radioactive disintegration, but this fails entirely to explain the enormously greater loss experienced by the sun. Furthermore, the earth's loss of mass is probably replaced many times over by falls of meteors and cosmic dust, but no one has ever suspected or suggested any source of replenishment of the masses of the sun and stars which is at all comparable with their known loss.

Thus the sun's loss of mass is cumulative and has in all probability gone on at its present, or at an even greater, rate throughout the whole of its vast age of some seven million million years. Indeed, astronomical evidence makes it fairly certain that younger stars radiate more energetically than older stars. When allowance is made for this, it is found that the sun must have radiated many times its present mass during its life of seven million million years; it must have been many times as massive at birth as it is now, and of every ton it originally contained only a few hundredweight remain to-day. Since no form of radioactive disintegration with which we are acquainted results in such a diminution of mass as this, we are forced to suppose that something still more fundamental is responsible for the sun's diminution of mass and emission of radiation. Of each thousand atoms that the sun contained at its birth only a few dozen remain to-day, and we can only conclude that all the rest have been annihilated and their mass set free in the form of radiation. This transformation of atoms into radiation, although unknown to terrestrial physics, must clearly be one of the fundamental physical processes of the universe.

THE UNIVERSE AS A HEAT-ENGINE

General thermodynamical theory shows that every natural system tends to move toward a final state of maximum entropy by steps such that, statistically speaking, the entropy increases with every step. In calculating this entropy, classical thermodynamics regarded the chemical atoms as indivisible, indestructible, and immutible; the system consisted merely of permanent atoms and energy, and maximum entropy was attained when this energy was partitioned between the kinetic and potential energies of the atoms and the energy of radiation traveling freely through space, in such a way that no possible redistribution could make the entropy greater.

Modern knowledge shows this scheme of thermodynamics to be totally inadequate. So far from atoms being the eternal unchangeable bricks of the universe, modern science finds them subject not only to constant change, but also to total destruction. Not only do their nuclei change their retinue of attendant electrons, but they themselves both crumble away into simpler nuclei, and dissolve entirely into radiation. Furthermore, energy can reside in other forms than those just enumerated; it can be used, stored, and transformed in changing electron orbits inside the atom, in breaking up atoms, in rearranging and breaking up the atomic nuclei and so transmuting the elements; it can be liberated by the complete annihilation of matter. Neither total energy nor total mass is any longer constant; the conservation both of mass and of energy has disappeared from physics, and only a kind of sum of the two is conserved.

THE END OF THE UNIVERSE

The final state of the universe must be such that the entropy can not be increased even by transmuting the elements or changing atoms into radiation. It could, of course, be calculated readily enough if the necessary new and enlarged scheme of thermodynamics were available, but competing schemes are in the field. The Bose-Einstein scheme leads to one result, the Fermi-Dirac scheme to another; the results on both schemes have been worked out by Jordan.[4]

The two schemes lead to the same result in one particular limiting case, and this limiting case happens to give a wonderfully close approximation to the state of the universe as a whole. The limiting case is that in which space is almost empty of matter, a specification which sounds like nonsense until we find some common standard by which an amount of matter may be compared with an amount of space. If we measure an amount of matter by the amount of space it occupies, then the "emptiness" of space is one of the commonplaces both of modern physics and of modern astronomy. It is not merely a question of the emptiness of the atom, which has already been noticed. Hubble[5] has estimated that if all the matter within about 100,000,000 light-years of the sun were uniformly spread out, it would have a mean density of the order of only about 10^{-31} gm. per cubic centimeter, so that even the very empty atoms would be at several thousand million times their diameters apart.

We can express this emptiness of space in a more fundamental manner. The energy set free by the total annihilation of 1 gm. of matter is equal to C^2 or 9×10^{20} ergs, so that the total annihilation of all the matter of the universe, assuming an average density of 10^{-31} gm. per cubic centimeter, would only provide an energy-density of 9×10^{-11} ergs per cubic centimeter, which would raise the temperature of space from absolute zero to about 10° abs. The emptiness of space is indicated by the lowness of this temperature in comparison with the temperatures, as shown in Table III, which are necessary to effect atomic and subatomic changes. If we make the approximation of neglecting 10° in comparison with the temperature of 2,200,000,000,000° which corresponds to the annihilation or creation of electrons and protons, the various schemes of statistical mechanics give the same result for the number of electrons and protons left undissolved into radiation. Independently of the size of the universe, the dominating factor in this number is $e^{-mC^2/RT}$; and as the index of the exponential is the ratio of the two temperatures just considered, the number is entirely negligible. Thus the final state of maximum entropy is one in which every atom has

[4] *Zeitsch. f. Physik.*, 41, 711; 1927.
[5] *Astrophys. Journ.*, 64, 368; 1926.

dissolved away into radiation, or at least every atom which is capable of so doing. This conclusion must, I think, be admitted quite independently of any particular scheme of statistical mechanics. The approximation that space is empty may be stated in the alternative form that the extent of space is enormously great; space, regarded as a receptacle for radiant energy, is a bottomless pit. In the terminology of the older mechanics, space has so many degrees of freedom that there can be no thermodynamical equilibrium so long as any energy is concentrated in matter. In more modern language, there are so many phase-cells associated with detached radiation, that the chance of any energy being found elsewhere is negligible.

The road by which the universe travels to this final state is disclosed by Table III. The last column is seen to contain entries only in its upper half; the temperatures necessary to effect the processes dealt with in lower half of the table are so high that, to the best of our knowledge, they are not to be found anywhere in the universe. When these latter processes occur, then, they are everywhere spontaneous; they are unaffected by the actual temperatures, and so absorb no radiation. Thus, the transformation, "mass ⟶ radiation," occurs everywhere, and the reverse transformation nowhere. There can be no creation of matter out of radiation, and no reconstruction of radio-active atoms which have once broken up. The fabric of the universe weathers, crumbles, and dissolves with age, and no restoration or reconstruction is possible. The second law of thermodynamics compels the material universe to move ever in the same direction along the same road, a road which ends only in death and annihilation.

THE BEGINNING OF THE UNIVERSE

The end of this road is more easily disconcerned than its beginning. The atoms which are now annihilating themselves to provide the light and heat of the stars clearly can not have existed as atoms from all time; they must have begun to exist at some time not infinitely remote, and this leads us to contemplate a definite event, or series of events, or continuous process, of creation of matter. If we want a naturalistic interpretation of this creation, we may imagine radiant energy of any wave length less than 1.3×10^{-13} cm. being poured into empty space; such radiation might conceivably crystallize into electrons and protons, and finally form atoms. If we want a concrete picture, we may think of the finger of God agitating the ether. We may avoid this sort of crude imagery by insisting on space, time, and matter being treated together and inseparably as a single system, so that it becomes meaningless to speak of space and time as existing at all before matter existed. Such a view is consonant not only with ancient metaphysical theories, but also with the modern theory of relativity. The universe becomes a finite picture whose dimen-

sions are a certain amount of space and a certain amount of time; the protons and electrons are the streaks of paint which define the picture against its space-time background. Traveling as far back in time as we can brings us not to the creation of the picture, but to its edge, and the origin of the picture lies as much outside the picture as the artist is outside his canvas. On this view, discussing the creation of the universe in terms of time and space is like trying to discover the artist and the action of painting by going to the edge of the picture. This brings us very near to those philosophical systems which regard the universe as a thought in the mind of its Creator, and so reduce all discussion of material creation to futility.

Both these points of view are impregnable, but so also is that of the plain man who, recognizing that it is impossible for the human mind to comprehend the full plan of the universe, decides that his own efforts shall stop this side of the creation of matter.

ATOMIC TRANSFORMATIONS

The transformation of uranium into lead and helium involves a drop of energy, but in the lighter elements the energy-change is in the reverse direction. Four atoms of hydrogen are more, not less, massive than an atom of helium, so that their energy-content is greater. Thus helium can never disintegrate spontaneously into hydrogen, although four atoms of hydrogen might spontaneously unite to form an atom of helium. They could not unite other than spontaneously, except possibly as a rare accident, since the temperature of transformation, 64,000,000,000°, is higher than occurs in the universe. Whether they ever unite even spontaneously remains an open question on which opinions differ. Millikan at one time suggested this process as the origin of the highly penetrating radiation which bombards the earth from outer space, but recent observations rule this interpretation out; the observed wave length of the radiation is too short, so that the radiation must originate in something more fundamental even than the transformation of hydrogen into helium. Whether any such process can be found, short of the complete annihilation of matter, remains to be seen; personally, I feel doubtful.

[*Added October 7, 1929.* Since the foregoing was written, Klein and Nishina have worked out a very complete mathematical theory of the absorption of radiation. According to this theory, the observed absorption of the highly-penetrating radiation indicates a wave-length of almost exactly 1.3×10^{-13} cms. for its most penetrating part. Thus this part, at least, would seem to originate directly in the annihilation of protons and their accompanying electrons.]

[*Added January 29, 1930.* The theory of Klein and Nishina has now been tested by Gray, Stoner and others, and is found to fit observation almost exactly. In view of this, it is exceedingly difficult to attribute the most penetrating radiation to any other source than annihilation of protons and electrons.]

Millikan has recently suggested that this radiation may result from electrons and protons falling together and forming atoms in

regions outside the stars. As a collection of oppositely charged particles could not remain uncombined for long, he postulates a continual creation of protons and electrons out of the stray radiation of the stars; matter is continually being annihilated in the interior of the stars, and re-created outside them. This gives a cyclic universe which might go on for ever.

Like all other cyclic universes, however, it clashes with the second law of thermodynamics. A universe which is not in a state of maximum entropy moves irreversibly along the path of increasing entropy and so can not be cyclic; one which is already in such a state must be macroscopically dead, and so can not be cyclic in any sense perceptible to us. Indeed, it is easy to find the exact spot at which Millikan's concept comes into confiict with the second law of thermodynamics; it is that we can not have protons and electrons transformed into radiation at a high temperature and then have the process reversed at a lower temperature.

Some may not regard this as a fatal objection to the scheme in question. All our discussion has been based on the supposition that the laws of physics remain valid at enormously high temperatures and under conditions entirely outside our experience. Consequently, all our conclusions can be avoided, and everything can be put back in the melting pot, by the single hypothesis that the laws which govern matter out in space differ from those which govern matter on earth. Yet we have only found it necessary to assume the simplest and most fundamental of physical laws, namely, the second law of thermodynamics and the broad general principles of the quantum theory; and it is hard to imagine that such wide laws fail outside our laboratories. The obvious path of scientific progress would seem to lie in the direction of inquiring what consequences are involved in supposing these laws to be of universal scope, and then testing these consequences against the ascertained facts of observational astronomy. So far as present indications go, astronomy, so far from challenging these consequences, goes half-way out to meet them.

Apart from transitory rearrangements of atomic electrons, the fundamental changes in atoms consist in transitions to states of lower energy. Under the classical electrodynamics, an electron describing a circular orbit of radius r about a charge E lost energy at a rate $\frac{2}{3}E^2a^2C/r^4$ (Larmor's formula), and this caused the radius r to decrease at a calculable rate; the charges inevitably and spontaneously fell towards one another. The quantum mechanics replaced this steady fall by a sequence of sudden drops, but according to Bohr's correspondence principle the rate of fall remains statistically the same, at any rate so long as the orbits are large, as on the classical electrodynamics; that is to say, the sum of the radii of the orbits of a whole crowd of atoms decreases through spontaneous jumps at just the same

rate as though their motion was governed by the old mechanics. The spontaneous degradation of energy we have had under consideration is now seen to be the natural extension into quantum territory of that implied in Larmor's classical formula. Had it not been for this degradation of energy, the atoms would have been perpetual motion machines; Larmor's formula prohibited that. The quantum theory seemed at first to remove the prohibition and reconstitute the atom a perpetual motion machine. Then came Einstein's famous paper of 1917, which made it clear that even under the quantum theory perpetual motion was banned; spontaneous degradation of energy was shown to be implied in Planck's formula for black-body radiation. Once again, then, perpetual motion disappears from physics, and the grit in the bearings, which ultimately brings the machine to rest, is the natural quantum theory analogue of that which would have brought the machine to rest in the classical electrodynamics. Long ago we used to call it the interaction between matter and ether.

There appears to be one exception. The classical electrodynamics ruled out perpetual motion machines entirely. The new physics also rules them out, but permits the conspicuous exception of atoms in their state of lowest energy; these can go on in perpetual motion to all eternity, because there is no state of lower energy to which they can drop.

Is this exception real or is it only apparent? In a sense a state of still lower energy is reached when the electric charges, let us say of the hydrogen atom, fall into one another and the atom dissolves into radiation. We could remove the apparent exception from the new physics, and dismiss perpetual motion machines entirely from science, by supposing that after moving for a certain very long time in its state of lowest energy the hydrogen atom dissolved spontaneously into radiation. This might be dismissed as mere idle speculation were it not that the most fundamental physical process in the universe as a whole appears to be precisely this spontaneous dissolution of atoms into radiation.

If this kind of spontaneous dissolution should prove to be the true mechanism of the transformation of astronomical matter into radiation, then clearly bare nuclei and free electrons must be free from annihilation. Thus the conjecture may claim some support from the circumstance that the "white dwarf" stars, in which the atoms are broken up completely, or almost completely, into their constituent nuclei and electrons, emit exceedingly little radiation; their substance would seem to be immune from annihilation. If the conjecture should ultimately prove its claim to acceptance, the main physical processes of the universe could all be included in one comprehensive generalization, and the speck of radium which we watch in the spinthariscope would symbolize all the happenings of the physics of the universe.

COUNTING THE STARS AND SOME CONCLUSIONS[1]

By Frederick H. Seares

Assistant Director, Mount Wilson Observatory, Carnegie Institution of Washington

[With 4 plates]

I

INTRODUCTION

Counting stars is not unlike counting people or sheep or pebbles on the seashore. The astronomer's difficulties are not in the counting, but rather in knowing when the counting must start and stop. With patience these difficulties may be overcome, but the conclusions to be drawn from the numbers of stars counted are a more delicate matter; some are indisputable, others less certain, still others highly speculative.

First of all, we are concerned with a census of the sky; and just as the census taker enumerates people in different ways—according to residence, race, occupation, for example—so the astronomer may count his stars differently; but, whatever the manner of counting, it has always the purpose of learning how the stars are scattered throughout space and how the great system which they form is constructed.

To keep clear of complexities and survey only the broad structural features of the system, he counts, at the start, in only two ways; to learn fundamental things, he considers characteristics which themselves are fundamentally different. At first, therefore, he observes only the direction of a star in the sky and its brightness as seen with the telescope. All other features in which stars differ, such as size, color, mass, motion, are left for subsequent study. It is as though the census taker were to count people according to their ages and the places in which they live, disregarding all other possible groupings, such as height, race, and occupation.

---

[1] Reprinted by permission, with minor changes, from Publications of the Astronomical Society of the Pacific, vol. 40, pp. 303–331, 1928. An address delivered before the Pacific Division of the American Association for the Advancement of Science, at the Pomona meeting, June 14, 1928. A detailed account of the investigations here described, which were undertaken in part with the cooperation and assistance of Prof. P. J. van Rhijn of the Kapteyn Astronomical Laboratory at Groningen, and of Miss Mary Joyner and Miss Myrtle Richmond of the computing division of the Mount Wilson Observatory, may be found in Mt. Wilson Contributions, Nos. 301, 346, and 347.

The sky has no naturally marked boundaries within which the stars may be counted and intercompared; but as far as direction is concerned, it is easy to find how many stars there are, say per square degree of the sky, in different parts of the heavens. The counting of stars according to brightness, however, is another matter.

The practical difficulty, as already stated, lies in recognizing the limits of brightness within which the stars are to be counted. To overcome this, a scale of brightness is required, with which individual stars may be matched to determine their light; for example, a sequence of stars, progressing by known steps, from the most brilliant in the sky to the faintest seen in our telescopes. Whatever the procedure adopted, it is essential that the unit of measurement be known in terms of the intensity of star light, because the intensity of the light received by the eye depends partly on the distances of the stars, and distances we wish very much to know. Initially, no such scale existed, and one had to be constructed.

The earliest records of the brightness of stars, which go back 1,800 years to the Alexandrian astronomer Ptolemy, represent rough eye estimates, expressed in a unit called a magnitude. To the brightest stars Ptolemy assigned the first magnitude; to those just visible to the unaided eye, the sixth magnitude; and to stars of intermediate brightness, magnitudes 2, 3, 4, and 5. When the invention of the telescope brought fainter stars into view, Ptolemy's scale was extended, still by simple eye estimates. At length, about a century ago, instruments for measuring the intensity of a star's light were devised, and then for the first time the physical equivalent of the unit of magnitude became clear. At this point it must be noted that magnitude is a measure of visual sensation—a very different thing from the intensity of the light which produces the sensation. On measurement it turned out that the intensity of Ptolemy's first-magnitude stars was about one hundred times that of stars of the sixth magnitude, and for convenience the simple relation thus approximately satisfied by Ptolemy's magnitudes was adopted as a precise definition of the unit of magnitude. As now used, therefore, the unit is such that a difference of five magnitudes corresponds exactly to a ratio of 100 to 1 in the intensities, whence a difference in brightness of one magnitude is equivalent to an intensity ratio of 2.512. A further detail is the beginning, or zero point of the scale of magnitudes, which must be the same everywhere in the sky, if the measures of brightness in different parts of the heavens are to be comparable. Again for convenience, the zero point adopted was such that the precisely defined magnitudes agree as closely as possible with the old values obtained by eye estimates.

Note now how this definition applies to faint stars. It means that a sixth-magnitude star is one hundred times as intense as one of the eleventh magnitude, and hence, that the first-magnitude star, as

compared with the eleventh, is 100×100 or 10,000 times as intense; if we extend the scale downward another 10 magnitudes, which brings us to the practicable working limit of large modern telescopes, the intensity ratio takes on another factor of 10,000, and we have for the interval of 20 magnitudes a ratio of 100,000,000 to 1. The light of a first-magnitude star is thus 100,000,000 times as intense as that of a star of the twenty-first magnitude. The numbers involved are to each other about as the distance separating California from New York is to a length of two inches.

The construction of the magnitude scale therefore requires the ultimate comparison of sources of light differing by an enormous ratio; in part, the undertaking is analogous to finding how many times a length of two inches is contained in a distance of about 3,000 miles, without having even a foot rule or an engineer's chain to start the measurement. Actually the photometric problem is far the more troublesome, for the unavoidable error in measuring the intensity of a light is much greater, proportionally, than that involved in measuring a length. Indeed it is so much the more difficult that, although the concept and definition of the magnitude scale have been clear enough for many years, it is only recently that some approach to practical realization has been made in the attempt to fix standard limits of brightness within which the stars may be counted.

Before turning to the results of counting, the impossibility of counting all the stars must be noted. The whole sky over, about 6,000 stars may be seen without a telescope; but among the fainter stars the numbers run into millions and hundreds of millions. For these even the simplest enumeration would be impossible, whereas much more than simple enumeration is required. In order to specify the group with which any star is to be counted, the scale of magnitudes must be applied to the star to measure its brightness, much as a yardstick might be applied to a man to determine his height. Only when this has been done can it be said that the star belongs with those whose magnitudes are between, say, 10.0 and 10.5. But measurements of brightness take time. At Potsdam Müller and Kempf spent 19 years in deriving the magnitudes of 14,000 stars. At Mount Wilson we have measured some 70,000 stars; but even with modern photographic methods, the labor involved represents the continuous occupation of several people for a number of years.

To avoid a task that could never be ended, we follow the plan first used for the star gauges of the Herschels and count only stars in representative regions of the sky. We deal with samples of stars, just as the census taker, if pressed for time, might count the inhabitants of only every other block, or perhaps of every fifth block, of a great city like New York, and still arrive at useful conclusions about the population of the city as a whole. In any such restriction of

the counting the samples must really represent the whole, a condition satisfied in practice by counting regions uniformly distributed over the sky, and, by using areas that are not too small. In general, much smaller areas may be used in counting faint stars than for stars of moderate brightness. Thus, for the very faint stars counted at Mount Wilson the sample regions are so small that their total area is less than a thousandth part of the sky. Notwithstanding the general sufficiency of small sample regions, it must not be supposed that the resulting counts are free from statistical irregularities. They are not; but those present are chiefly of a local character, and may be smoothed out by averaging the counts in several neighboring regions.

II

THE GENERAL FORM OF THE STELLAR SYSTEM

From these general considerations, we turn to some of the results of counting, noting at once an important conclusion which follows, not from the actual numbers of stars counted, but from the size of the sample regions which is sufficient for the counting. If counts covering a total area of only a thousandth of the whole sky give useful information, then the stellar system must possess much structural unity and regularity. Otherwise, small sample regions chosen at random could not reveal as they do the underlying structural features of the system.

The first peculiarity to be noted in the counts themselves is the extraordinary rapidity with which the numbers of stars increase as we pass to fainter and fainter limits of brightness. Four photographs of the same region (pl. 1), exposed just long enough to show stars brighter than the twelfth, fifteenth, eighteenth, and twentieth magnitudes, respectively, are perhaps as impressive as the numbers themselves.

Another peculiarity is that the stars are most numerous in the Milky Way and decrease in numbers as we count in regions more and more distant, in either direction, from this cloud-like band which encircles the sky. This also is well shown by photographs (pl. 2) which record stars to the same limit of brightness in the two regions, one in the Milky Way itself, the other far distant therefrom. The phenomenon is so striking, and the changes in the numbers on the two sides of the Milky Way are so similar, that it suggests, as it did to Sir William Herschel, a symmetrical arrangement of the stars about the plane passing through the Milky Way clouds. The regularity of the system already inferred from the sufficiency of small sample regions as an indication of stellar distribution thus becomes the regularity of a symmetrical arrangement in which the Milky Way stands out as the framework of the system.

TABLE I.—*Mean distribution of stars*

[Number of stars per square degree brighter than photographic magnitude m at different distances from the Milky Way]

m	Galactic latitude				Galactic concentration
	0°	30°	60°	90°	
4.0	0.0156	0.00741	0.00514	0.00452	3.5
5.0	0.0449	0.0214	0.0148	0.0130	3.4
6.0	0.128	0.0614	0.0421	0.0372	3.4
7.0	0.361	0.173	0.118	0.103	3.6
8.0	1.01	0.482	0.325	0.278	3.6
9.0	2.81	1.31	0.871	0.723	3.9
10.0	7.71	3.49	2.23	1.81	4.3
11.0	20.8	9.06	5.47	4.33	4.8
12.0	55.6	22.7	12.8	9.89	5.6
13.0	146	54.4	28.6	21.4	6.8
14.0	371	125	61.0	44.3	8.4
15.0	910	272	123	87.1	10.4
16.0	2,140	561	236	163	13.2
17.0	4,780	1,090	428	288	16.6
18.0	10,200	1,990	733	482	21
19.0	20,800	3,440	1,190	769	27
20.0	40,100	5,620	1,820	1,160	34
21.0	73,600	8,690	2,650	1,670	44

To study these phenomena more closely it is customary to average for each limit of brightness all the counts in the Milky Way and tabulate the results; then, similarly, to average and tabulate the counts along circles parallel to the Milky Way, on either side and separated from it by intervals[2] of 5° or 10°. The result is a "mean distribution table" (Table I). The numbers in the first column are the magnitude limits to which the stars are counted; those in the second, the average numbers of stars per square degree in the Milky Way brighter than the successive limits, while the following columns give similar averages for circles parallel to the Milky Way in latitudes 30°, 60°, and 90°.[3]

Table I recognizes the symmetrical arrangement of stars on the two sides of the Milky Way in that it applies to either side, and, in fact, is the average of the counts in the two halves of the sky. It shows the rapid increase in the numbers of stars with increasing magnitude, the general crowding of the stars toward the Milky Way, and now, a third peculiarity, namely, that the crowding is much greater for faint stars than for bright ones and increases regularly with the limiting brightness. This is revealed by the numbers in the last column, which are the ratios of the average counts for latitudes 0° and 90°. Thus the first line of the table shows three and five-tenths times as many stars in the Milky Way as at latitude 90°;

[2] Angular distances measured on the sky perpendicular to the great circle through the Milky Way clouds (the galactic circle) are called galactic latitudes. Angular distances measured along the galactic circle from a certain starting-point are galactic longitudes. These coordinates are analogous to terrestrial latitude and longitudes used to define the position of points on the earth.

[3] For convenience the logarithms of the numbers, rather than numbers themselves, are often tabulated. One square degree is equivalent to about five times the area of the sky covered by the sun or the full moon. For brevity Table I gives results for only four values of the galactic latitude. A more extended table may be found in Mt. Wilson Contr. No. 301 (Table XVII) or in Contr. No. 346 (Table XIV).

but for the much fainter limit in the last line, the ratio is more than 40 to 1.

The general crowding of stars toward the Milky Way has been known since the time of the Herschels, but the relatively great concentration shown by the faint stars, although long suspected, was first definitely established only a dozen years ago by counts made at Mount Wilson. That so conspicuous a feature of the distribution could remain long in doubt illustrates the uncertainty attached to the magnitude scale then available. This, it was feared, might be affected by an error depending on distance from the Milky Way, which would modify the relative numbers of stars counted in the Milky Way and elsewhere, and hence render any estimate of the concentration uncertain.

Let us now try to picture what these peculiarities in the counts of stars mean. Table I shows that each extension of the counts over an additional magnitude increases the total number of stars visible in any direction from two to three times. The exact increase is important and is therefore shown in Table II in detail for different parts of the sky. The quantities in this table are nothing but the ratios of the numbers standing above each other in Table I. Thus from the second column of Table I, 0.0449/0.0156 = 2.88; 0.0128/0.0449 = 2.85, etc. The several quotients 2.88, 2.85, etc., appear in succession in the second column of Table II, while similar ratios for other parts of the sky are in the remaining columns. These ratios vary smoothly over the sky, and range from about 3 for bright stars near the Milky Way to 1.4 for faint stars at 90° distance from the galactic circle.

TABLE II.—*Star ratios*

[Factors by which total numbers of stars counted to limiting magnitude *m* are multiplied when the counts are extended one magnitude]

m	Galactic latitude			
	0°	30°	60°	90°
4.0				
5.0	2.88	2.89	2.87	2.88
6.0	2.85	2.86	2.85	2.85
7.0	2.82	2.82	2.81	2.77
8.0	2.80	2.78	2.75	2.70
9.0	2.77	2.72	2.68	2.60
10.0	2.75	2.67	2.56	2.50
11.0	2.70	2.59	2.45	2.39
12.0	2.67	2.50	2.34	2.29
13.0	2.62	2.40	2.23	2.17
14.0	2.55	2.29	2.13	2.07
15.0	2.46	2.18	2.02	1.97
16.0	2.35	2.06	1.91	1.87
17.0	2.23	1.94	1.81	1.77
18.0	2.13	1.83	1.71	1.68
19.0	2.04	1.73	1.62	1.60
20.0	1.93	1.64	1.54	1.51
21.0	1.84	1.55	1.45	1.43

The rapid increase in the numbers of stars with increasing magnitude recalls the old problem of the cost of shoeing the horse, with a penny for the first nail, two for the second, four for the third, and so on. Doubling the cost for each successive nail runs the total into an incredible sum; but with the stars, as shown by Table II, the numbers, on the whole, are rather more than doubled each time an additional magnitude is counted. No wonder the total is great.

To illustrate further the meaning of Table II, imagine a small stellar system in which the individual stars are candles, all alike and equally spaced, we ourselves being at the center of the system. With the eye alone we should be unable to see candles beyond a certain distance, because the light reaching the eye would be too faint to produce a visual sensation. A telescope, however, would bring some of them into view; and for the purpose let us choose an instrument just powerful enough to reveal candles exactly one magnitude fainter than the faintest seen without the telescope. The relation between intensity and brightness which defines the unit of magnitude tells us that such a telescope would penetrate about one and six-tenths times farther into space than the unaided eye. Now let us count all the candles visible from our central station, both with and without the telescope. The numbers will be those contained in the two spheres whose radii are to each other as 1 to 1.6, and, since the candles are everywhere equally spaced, their ratio will be equal to that of the volumes of the two spheres, or very nearly 4 to 1. Under the conditions supposed, we must therefore expect that extending the counts of candles by one magnitude would multiply the number visible by 4.

Now, since the star ratios of Table II nowhere equal this theoretical value and, for the most part, are far below it, there must be some essential difference between the real stellar system and the miniature system of candles. Candles, to be sure, are not stars; but for the moment that is not an essential difference. Stars, on the other hand, may not all be of the same candlepower, as the candles are. In fact, they are not; but it can be shown that this also is not the explanation. Again, some of the distant stars may be hidden by haze and dust scattered throughout space. This certainly would reduce the ratios of the numbers counted and actually may have some effect on their values; but the presence of absorbing material seems at most to be a local phenomenon, and can not be the complete explanation. The only other significant factor is a possible lack of uniformity in the spacing of the stars, and this indeed is where the difference lies. Uniform spacing means a factor of 4; but if the stars should thin out with increasing distance from our station in space, the numbers of faint stars would be less than we should otherwise find, and the ratios from magnitude to magnitude would necessarily be less than 4. The converse is equally true, and since in the stellar system the increase

is less than fourfold when the counts are extended by a magnitude, the stars must thin out with increasing distance from the point of observation; further, the more the factor drops below 4, the faster does the thinning out take place.

Consider now more in detail the ratios in Table II, and first, those in the second column, corresponding to directions toward the Milky Way. From what has been said it follows that the brightest of these stars thin out with increasing distance, while the faint stars, which, as a whole, are at much greater distances, thin out even more rapidly. Consider now the last column, referring to the direction perpendicular to the plane of the Milky Way. Here the ratios are generally smaller than those standing opposite them in the second column, which leads to the important conclusion that the stars in this direction not only thin out, but thin out very much faster than they do toward the Milky Way.

The statement that the stars thin out with increasing distance often rouses the feeling of an implied contradiction with the rapidly increasing numbers of Table I. Discrimination as to what is meant sets the matter straight, however. The conclusion that the stars thin out means only that the number of stars per unit volume decreases with increasing distance; while the total number of stars counted depends on the density, it also depends on how many units of volume are included. Thus in the case of the candles, the extension of the counts by one magnitude gives a total which includes all the candles in a volume four times that which the eye alone can survey. The additional volume made accessible by the extension is therefore three times that already known to the unaided eye; the density of candles in the added volume might therefore drop to one-third that near the center of the collection and the total number visible would still be doubled by extending the counts.

In brief, therefore, Table II indicates that the stars of our system are not equally scattered in space, but thin out in all directions with increasing distance from the point at which we make our observations, least rapidly in directions toward the Milky Way and fastest in a direction perpendicular to its plane.

The table also suggests another inference with respect to the stellar system in that the ratios steadily decrease as the magnitude limit is extended downward. If this decrease continues for stars beyond the reach of existing telescopes, the ratios themselves must eventually become zero. Hence for some low limit of brightness no more stars will be added when we attempt to extend the counts to a still lower limit; the total number of stars in the system is therefore limited.

The evidence afforded by star counts alone does not fully establish this inference as a fact, for the counts do not indicate with certainty the relations among fainter and still undiscovered stars; the extra-

polation is too great. The conclusion itself, however, is well founded, but the proof comes from evidence other than star counts. This being the case, we may accept the conclusion and thus arrive at the certain result that the numbers in Table II would eventually become zero were the table sufficiently extended.

If the limiting magnitude for which this occurs were accurately known, we should be able to estimate with fair approximation the total number of stars in the system. As it is, we know that such a limit exists, but the only guide to its value is the rate of decrease in the ratios of Table II. This rate is slow, and as the ratios for the faintest stars known are still rather large, the magnitudes for which they become zero, in different directions in the sky, are very uncertain.

Any attempt to learn the total number of stars in the system by extrapolating Table II can therefore lead only to the roughest sort of an estimate. About a thousand million stars are within reach of the 100-inch reflector. If the invisible stars behave as those accessible to observation would lead us to expect, the total number in the system must be some thirty times greater, or of the order of 30,000,000,000. The uncertainty of this result is illustrated by the fact that the estimated total in the direction of the Milky Way is about seventy times the number of stars actually counted.

The stellar system thus appears to be a limited collection including many thousand million stars; as a first approximation it may be thought of as having the form of a much-flattened swarm of bees, with the densest part of the swarm at the center. The rate at which the stars thin out in different directions shows that the greatest extent of the system is in the direction of the Milky Way and equal to some six or seven times its thickness. The actual linear dimensions are very uncertain. Indeed they lie outside the conclusions that may be derived from star counts alone; but for completeness it may be added that two or three lines of evidence suggest values of two to three hundred thousand light years for the diameter in the plane of the Milky Way, although even larger values are by no means excluded. The gradual thinning out of the stars probably means that no sharply marked boundary exists, just as none exists for the upper limit of the earth's atmosphere. Star counts, supplemented by other information, do tell us, however, something about the distance at which the number of stars per unit of volume drops to a given value, say to 1 per cent of what it is in our own neighborhood. Thus we should probably have to travel out in the direction of the Milky Way at least 30,000 light years, on the average, before we reached the point at which the stars had thinned out to this extent. In the direction perpendicular to the Milky Way the distance would be much less—perhaps 4,000 or 5,000 light years.

III

ECCENTRIC LOCATION OF THE SUN—DIRECTION OF THE CENTER

The symmetry found in the distribution of stars on opposite sides of the Milky Way shows that the sun and its planets must be close to the plane passing through the Milky Way and the center of the system; but it does not follow that they are close to the central point of the system. The mean distribution table (Table I) was prepared chiefly as a means of studying how the stars crowd together toward the Milky Way. In order to smooth out local irregularities in distribution as much as possible, counts all around the sky in the Milky Way, and in circles parallel to the Milky Way, were combined into single averages, one for each latitude; further, the results for the two halves of the sky were also averaged. This procedure was well suited to the purpose then in view, and led to the conclusions already stated. But now we must see if the averaging process has concealed anything of importance.

This inquiry has point because it is known that the stars are not equally numerous in all parts of the Milky Way. The irregularity meant is not the rapid fluctuation in numbers shown by the cloud-like grouping of stars, but a more fundamental difference revealed by the exceptional size and richness of the star clouds in the general direction of Sagittarius as compared with those in the opposite part of the sky. Because of this difference, it has often been suggested that the solar system may indeed be at some distance from the central point of the system. If so, slow progressive changes should appear in the counts along the Milky Way, and in fact, along any parallel circle, up to a high galactic latitude. We therefore turn again to the original counts in order to see whether they show any such change when these circles are followed around the sky.

In studying the crowding of stars toward the Milky Way, we concentrated attention on this one feature of the distribution by dealing with the average of the counts in all longitudes. This eliminated any influence arising from the possible progressive change with longitude in which we are now interested. And now we avoid any disturbance which might arise from the crowding toward the Milky Way by comparing only counts of stars in the same latitude, and, of course, to the same limit of brightness. A simple procedure is to compare, for a given latitude, the number of stars actually counted in each region with the average number for the whole circuit of the sky, and then to see whether the differences show any progressive variation. Finally, to test the results we may make independent comparisons for several different latitudes and for a number of limits of brightness.

Figure 1 illustrates the results for the stars brighter than the sixteenth magnitude, in general for every 10° up to latitude 70° on either

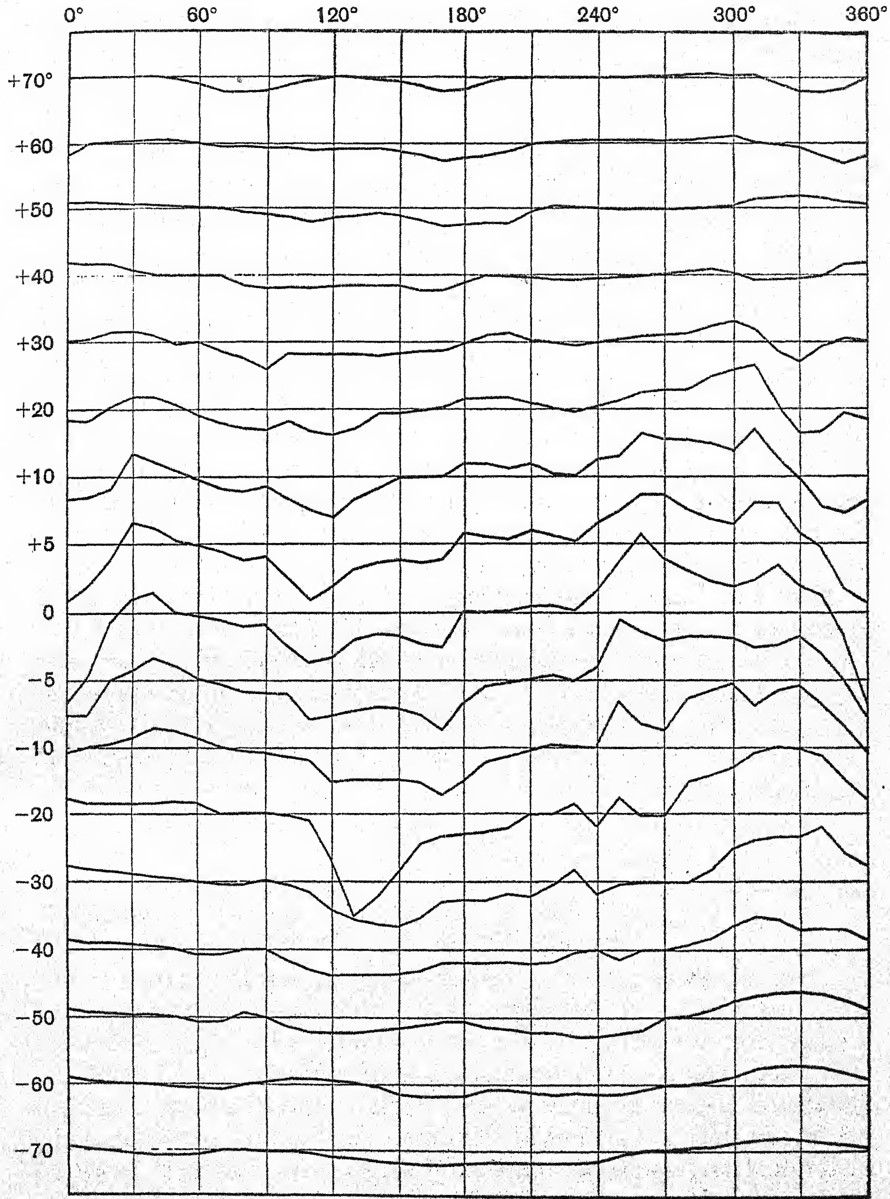


FIGURE 1.—Deviations of the observed numbers of stars in different parts of the sky from the average numbers shown in Table I. The stars here considered are brighter than magnitude 16.0; the general similarity in the curves for all galactic latitudes (figures on the left), with low points around longitudes 120° to 160° (figures at top), and high points around 300° to 350°, indicates that the center of the system of these stars is in longitude 319°

side of the Milky Way. Similar diagrams, showing very similar curves, were also prepared for limiting magnitudes 9. 0, 11.0, 13.5, and 18.0. Positions along the Milky Way, or along one of the parallel circles identified by the galactic latitudes on the left of the diagram, are indicated by longitudes at the top, measured from a standard meridian, just as in the case of longitudes on the earth. Portions of curves which lie above the horizontal axes mean that the observed numbers of stars in the corresponding regions of the sky are greater than the average number for the whole circuit; points below the axes represent observed numbers which are less than the average.

In spite of numerous irregularities, most of the curves show a general similarity in that in longitudes 240° to 360°, and on to 60°, they lie above their respective axes, while in longitudes 60° to 240° they drop below. This general statement disregards a conspicuous drop in the curves for low latitudes near longitude 360°. This irregularity must be disregarded, for it represents the great rift between the two branches of the Milky Way, where the number of stars counted is not representative of those probably present. There, we have reason to believe, great numbers of stars are blotted out by obscuring clouds of dust and nebulous material.

With allowance for this anomaly, a systematic departure from the average numbers of stars is c'early revealed in the counts, which can be traced to a great distance from the Milky Way. Figure 1 shows that in all latitudes we have counted the largest number of stars in the same general longitude, the smallest in the opposite longitude. The longitudes of the richest regions found by a numerical discussion of the data run as in Table III.

TABLE III

Latitude	0°	5°	10°	20°	30°	40°	50°	60°	70°	
Longitude	303	301	298	301	307	334	336	299	277	north of M. W.
		317	328	328	332	331	345	354	340	south of M. W.

These numbers are by no means equal; indeed they range over a good many degrees, especially in high latitudes. But it must be remembered that the stars are not distributed with exact uniformity and that local and purely random irregularities tend to obscure any structural feature, however important, when we attempt to trace that feature in limited portions of the data. In the present instance the individual longitudes cluster around a mean value of 319°, with an average departure of 15°. Local deviations from uniformity in the distribution fully account for the scatter in the individual values, whence we conclude that we have brought to light something fundamental in the arrangement of stars in space. The importance of the phenomenon becomes clear only when we translate the deviations in longitude into numbers; then we find that nearly five times as many

stars are visible in the direction of longitude 319° as in the opposite direction.

The accordance of the results in Table III, the progressive change in the curves of Figure 1 with longitude, and the fact that they flatten out with increasing distance from the Milky Way, all indicate that we are really at some distance from the center of the flattened system of stars. Indeed, we do not hesitate to accept this as a valid explanation of the phenomena. The direction of the center itself must of course agree with that in which the stars are most numerous, and is therefore to be looked for near longitude 319°, in Sagittarius, where, as already noted, the richest star clouds are found.

It is natural to ask next how far we are from the center; but this turns out to be a very difficult question, not yet fully settled. The attempt to answer it has, however, brought to light new features of stellar distribution to which we now turn our attention.

IV

DEPENDENCE OF CENTER AND SECONDARY GALAXY ON LIMITING MAGNITUDE OF COUNTS

Since the curves for the other magnitude limits have the general appearance of those for the sixteenth magnitude shown in Figure 1, they support the conclusion that the sun and planets are not at the center of the stellar system. The results for the direction of the center are remarkable, however, in that the mean longitude as found from the different series of curves is not constant, but shows a large progressive change with limiting magnitude. Thus for stars brighter than the ninth magnitude, the center seems to be in longitude 270°; as we extend the counts to fainter limits, the direction changes slowly but regularly along the Milky Way some 50° toward the east, until for the eighteenth magnitude we find it about where, a moment ago, we thought it actually to be located.

It is probable that the true center is indeed very nearly in this direction, and that its apparent dependence on magnitude arises from some peculiarity in the distribution of the brighter stars. When we consider counts which include only bright stars, this peculiarity asserts itself and spoils our calculation; when we add the faint stars, however, which are vastly more numerous than the bright ones, the peculiarity, whatever it may be, has little influence on the general distribution, and we find very nearly the true direction.

This conclusion is strengthened by considering a feature of the curves of Figure 1 which is not to be traced with the eye alone, but which appears clearly and consistently when we deal with the numbers themselves. It consists in a small difference between curves for the same latitude on opposite sides of the Milky Way of the kind to be expected were the stars symmetrically distributed not with respect

to the Milky Way, but about a plane slightly inclined thereto. Thus far we have thought of the stars as all tending to crowd toward the Milky Way; but now apparently we must admit that some of them cluster about another circle, a little tilted with respect to the Milky Way. Since we sometimes speak of the Milky Way itself as the galaxy, we call this new circle the secondary galaxy.

The small differences existing between curves for equal and opposite latitudes may be used to compute the amount and the direction of the tilt of the secondary galaxy; and since several pairs of curves are available for each limiting magnitude, a number of independent solutions may be made, the accordance of which will test the reality of the results. Since the existence of a secondary galaxy modifies slightly the longitudes already found for the center of the system, these must be redetermined when the position of the secondary galaxy is calculated. The complete results for limiting magnitude 16 are shown in Table IV.

TABLE IV

Latitude	0°	5°	10°	20°	30°	40°	50°	60°	70°	Average deviation
Longitude of center	303	310	317	318	324	332	341	334	322	± 9°
Tilt		3.8	5.6	3.9	4.9	4.6	1.6	3.1	5.6	± 1
Longitude of tilt		362	357	358	352	329	368	392	367	±12

Here again, the agreement in values derived from different latitudes is all that can be expected. The mean for the tilt is 4°, in longitude 357°, with a scatter in the individual values so small as to leave no doubt as to the general result.

When we extend the calculation to other limiting magnitudes, however, we find that the secondary galaxy is no more a fixed thing than is the direction of the center of the system, and, like the direction of the center, depends on the limit of brightness to which the stars have been counted. From counts to the eighteenth magnitude we find a secondary galaxy which deviates but little from the Milky Way; and had we counts to the twenty-first or twenty-second magnitude, we should probably find practical coincidence. Counts to other limits show, however, a very appreciable departure and a progressive change in the position of the secondary galaxy, which attains its greatest inclination to the Milky Way when only bright stars are included in the calculation. Figure 2 illustrates the results found from the Mount Wilson counts, and some by other observers from other data, plotted to show the changes in the direction of the center (L) and in the position of the secondary galaxy (p, tilt of plane; L_0, direction of tilt).

These calculations afford opportunity for a closer comparison of the numbers of stars on opposite sides of the Milky Way. Ex-

pressed as a ratio of the numbers on the north side to the numbers on the south, the results run as follows:

Limiting magnitude	9. 0	11. 0	13. 5	16. 0	18. 0
Ratio, north to south	0. 67	0. 75	0. 77	0. 98	1. 01

Here again is a change with limiting brightness. Counting only to the ninth magnitude, we find 50 per cent more stars in the southern half of the sky than in the northern. As fainter stars are added, the excess decreases and disappears near the sixteenth magnitude. From there on the numbers in the two halves of the sky are sensibly equal. Moreover, the ratios for individual zones in equal latitudes,

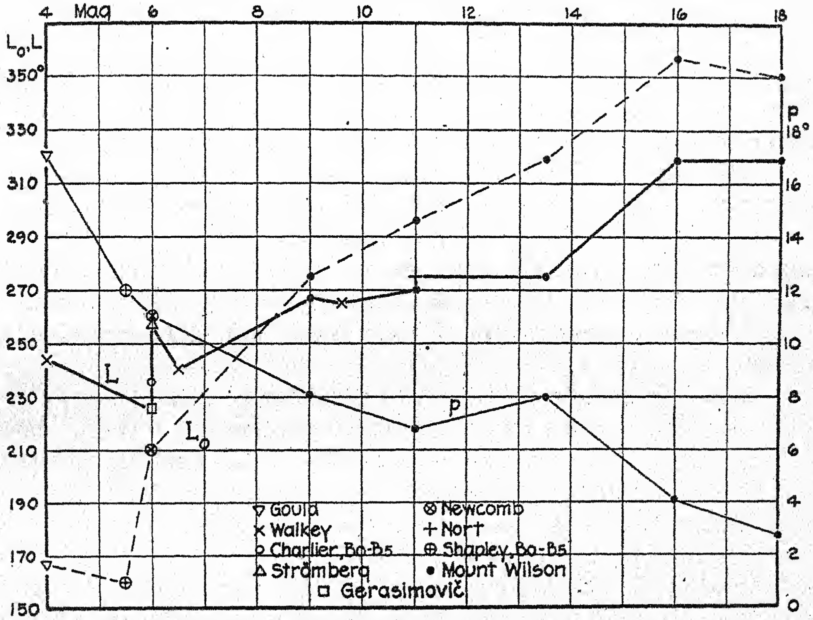


FIGURE 2.—L is the longitude of the center of the stellar system as derived from stars brighter than various limits of magnitude; p and L_0 are the tilt with respect to the Milky Way, and the direction of the tilt of the circles (secondary galaxy) about which the stars are symmetrically situated and toward which they tend to crowd

north and south, show a similar sequence of values; hence, although the distribution of bright stars in latitude is notably asymmetrical, that of faint stars is very symmetrical.

V

THE LOCAL SYSTEM

The probable explanation of these changes with magnitude is suggested by following the curves of Figure 2 back to about the sixth magnitude, for there we come to figures with which we are familiar in another connection. Immediately surrounding us in space is a large

collection of very hot, massive stars, mostly brighter than the sixth magnitude, having very conspicuous lines of helium in their spectra. These bright helium stars lie close to the Milky Way and constitute a local cluster, very much flattened—so much so, in fact, that the cluster is little more than a thin sheet of stars, extending out a thousand light years or so in the general direction of the Milky Way. The sun and planets lie a little outside the thin layer of stars, and at a distance of about 300 light years from the center of the collection. The direction of the center is in longitude 236°; the tilt of the plane about which the helium stars cluster is 12°, in longitude 160°. These figures are nearly those shown by Figure 2 for the center of the system and for the position of the secondary galaxy derived from counts of all kinds of stars to the sixth magnitude. The agreement is too close to be simply coincidence, and we conclude that most, if not all, of the stars brighter than the sixth magnitude bear some close relation to the local cluster of helium stars. That the bright helium stars do form a localized cluster is easily recognized from their physical characteristics, which cause them to stand out from their neighbors as a unit. Since the stars brighter than the sixth magnitude, as a whole, are symmetrically distributed about the same plane as the helium stars, the inference is that most of them belong to that cluster, and that together they constitute a local system of which the helium stars are only the nucleus.

Apparently, therefore, we must amplify our picture of the stellar system by supposing that a secondary aggregation of stars—the local system—exists within the larger system. The local system lies near the plane of symmetry of the larger system, but at a great distance from the central point. Like the larger system, it is flattened; its plane of symmetry is tilted 12° to that of the larger system. We ourselves are within the local system, 300 light years from its center situated in longitude 236°; the far more distant center of the larger system seems to be in longitude 325°, a little to the east of that indicated by the stars brighter than the eighteenth magnitude.

Looking out on the sky, we see the intermingled stars of both systems. When we count the stars to the sixth magnitude only, we deal chiefly with those of the local system, and hence find them crowding toward the secondary galaxy marked by the thin stratum of bright helium stars; the center appears to be in longitude 236°, because that is the direction of the center of the local system. When we extend the counts to a fainter limit, we add many stars belonging to the larger system, and thus introduce the characteristics of that system. The resulting distribution is not that of either system alone, but something in between; the secondary galaxy is less inclined to the Milky Way, while the direction of the center has shifted a little eastward along the Milky Way toward that of the larger system. But

when we count to a very faint limit, we include such enormous numbers of stars belonging to the larger system that the local system has no appreciable influence on the observed distribution; the stars crowd toward the great fundamental plane of the Milky Way, and the center appears in its true direction toward Sagittarius, in longitude 325°.

Finally, if we suppose the local system to be a little to the south of the plane through the Milky Way clouds, and the sun almost exactly in this plane, we account for the relative numbers of stars on opposite sides of the Milky Way—an excess of bright stars to the south, and an equal division of faint stars between the two halves of the sky.

The star counts even tell us something about the size of the local system, for both Figure 2 and the relative numbers of stars north and south of the Milky Way (p. 197) show that the influence of this system can be traced down to about the sixteenth magnitude. From this circumstance alone it seems likely that we should still find stars belonging to the local system at a distance of 10,000 light years from the sun. Other features of Figure 2, supplemented by other information, indicate that the members of the local system are to be counted by many millions, and that they comprise something like three-fourths of all the stars in our immediate neighborhood in space; the larger system would thus contribute only a fourth of the total stellar population near the sun.

The dominating influence of the local system may be shown very simply by examining star counts in another way. In studying the numbers of stars added by extending the counts downward, magnitude after magnitude, the results in different longitudes, as already explained, were averaged. To gain a general idea of how stars are scattered throughout space, we ignored the fact that we might not be at the center of the system, and were led by the ratios in Table II to conclusions which likened the stellar system to a much-flattened swarm of bees, thinning out in numbers from the center toward the edge. Now, however, we know that we are far from the center of the swarm; and it seems likely that were we to proceed in the direction of that point, we might find the stars crowding together, while in the opposite direction we should find them thinning out even more rapidly than the average counts indicate. This at least would be the expectation were it not for the presence of the local system.

When we turn again to the original counts to see how those in different directions along the Milky Way increase in numbers as we add fainter and fainter stars, we find that they build up much faster in the direction of the center than toward the opposite point in the sky, but not nearly fast enough to indicate any crowding of stars as the center is approached. On the contrary, the ratios are such that, as we leave our neighborhood in space, the stars must begin to thin out almost at once, whatever the direction in which we proceed out-

ward; they thin out least rapidly when we move toward the center, faster when we travel in the opposite direction, and fastest of all when we proceed toward the poles of the Milky Way. The significant detail is the behavior in the direction of the center of the larger system, which turns out to be just the opposite of that to be expected were the local system not present. We thus conclude, not only that a local system exists, but that it dominates the situation to such an extent that the characteristic distribution within the larger system which we expected to find is totally obscured. How completely this is the case is illustrated by the uppermost curve of Figure 3, which shows the numbers of stars per unit volume at different distances from the sun in two different directions, one (left) toward the center of the larger system, the other (right) in the direction diametrically opposite. Distances of points on the curve above the bottom of the diagram represent numbers of stars. Even toward the center, the stars thin out so rapidly that at 2,000 parsecs (6,500

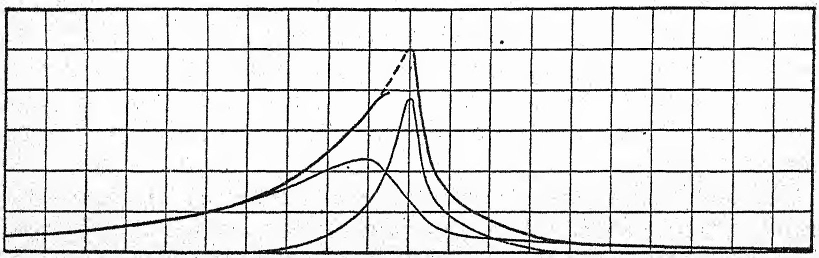


Figure 3.—Variation in the number of stars per unit volume at different distances from the sun (figures at bottom) in the direction of the center of the stellar system (toward the left) and in the opposite direction. The upper curve includes all stars together. This can be resolved into two other curves, one, nearly symmetrical, representing the local system, and another representing the larger system. Distances in parsecs may be expressed in light years by multiplying by 3.26

light years) the density is only one-half that near the sun, while at 5,000 parsecs (16,250 light years) it is only one-fifth. The great concentration of density near the sun represents the influence of the local system.

However we approach the matter, therefore, the larger system, in our own vicinity at least, seems to sink into a position of relative unimportance, and, when we attempt to learn more about it, we meet with great difficulties.

VI

SEPARATION OF THE LOCAL AND LARGER SYSTEMS

To proceed, we must try to get rid of the local system by removing its members from our counts. This is a hazardous undertaking, because, in general, we can not specify the system to which any given star belongs; and we are thus obliged to make an assumption, namely,

that the local system is symmetrical about a central point, or at least that it is not highly asymmetrical. Stated in another way, though rather crudely, we suppose that the point within the local system where the stars are thickest is not far from its geometrical center. Such an assumption is not without inherent probability, for most aggregations of stars seen in the sky possess a rough symmetry of this kind; and within the local cluster itself, in the nucleus of helium stars, we find evidence of its presence.

The operations involved in separating the local and larger systems are illustrated by Figure 3, where, as already explained, the uppermost curve represents the variation in the number of stars per unit volume in the direction of the center and of the point diametrically opposite. From the densities corresponding to this curve we must subtract those contributed by the local system. By the assumption just made, these will be represented by a curve, nearly symmetrical, having a maximum coinciding closely with the sun. The size and shape of the curve are not otherwise specified, and the choice of a definite form is beset with uncertainty. Nevertheless, certain guiding principles may be laid down: Thus, the central density of the local system, represented by the height of the maximum of the symmetrical curve, must be greater than some minimum value; otherwise, after the local system has been removed, the region of maximum density in the larger system will remain near the sun, which is at variance with all our ideas as to the structure of the system. On the other hand, the central density of the local system can not exceed a certain amount without leaving in the larger system, close to the sun, a region of abnormally low density. Finally, the relation between density and size in the local system must be such that the change in density in the larger system revealed by removing the adopted local system is everywhere smooth.

The result of the analysis is shown by the two component curves in Figure 3. Under the circumstances described we should scarcely expect more than a qualitative indication of relations; nevertheless, the central density and the diameter thus found for the local system are in general numerical agreement with the results derived from Figure 2, namely, a density of three-fourths the total near the sun and a diameter of six or eight thousand parsecs. Further, the curve for the larger system shows an increase in the density in the direction of the center, as we should expect, but, surprisingly enough, the stars seem to reach their highest concentration at a distance of only 3,000 to 6,000 light years, according to the degree of asymmetry admitted in the local system.

The position of this maximum must be far short of the geometrical center of the system; and even where thickest, the concentration of stars is only about one-half that at the center of the local system.

Regarded as the dominant portion of so vast a collection as the larger system, the region of maximum stellar concentration is not an impressive feature; and our instinct for symmetrical arrangements in the heavens makes us reluctant to accept this off-sided aggregation as the nucleus of the larger system, or the very unsymmetrical curve of Figure 3 as an indication of how the stars in this system are distributed.

VII

THE ANALOGY WITH SPIRAL NEBULÆ

At first sight it seems difficult to reconcile the improbabilities thus brought to light with the symmetry for which we instinctively look. Nevertheless, we are not without helpful suggestions. The trend of cosmological thought in recent years has been in the direction of analogies between the stellar system and the great spiral nebulæ like Messier 33 or Messier 101 (pl. 3). In form, there is close resemblance. In both cases the outline in the principal plane is roughly circular; and, seen edge-on (pl. 4 a, b, c), the spirals show the flattened contour found in our own system. Further, photographs made at Mount Wilson by Hubble with the 100-inch reflector (pl. 4) show that at least some of these nebulæ are gigantic systems of stars, composed of different classes of objects—diffuse nebulosity, novæ, Cepheid variables, and ordinary giant stars of different spectral types, which, class for class, correspond to those of the system about us; and, finally, that the nebulæ, if not actually as large as the stellar system, are nevertheless of the same general order of dimensions.

Seen broadside (pl. 3), the curving arms of the spirals, with their irregular knots and condensations of stars, lack the smoothness of distribution that counts in our own system seem to suggest; but it requires little imagination to realize that were we situated in the central plane of a spiral like Messier 33, we should find the scattered aggregations of stars blending into an encircling band of Milky Way clouds, with irregularities perhaps no greater than those in the star clouds of our own galaxy. Again, the conspicuously bright central condensation which is characteristic of the spirals makes us wonder if the cosmological analogy is complete, for thus far we have looked in vain in our own system for anything resembling a dominant central nucleus. But even this seemingly well-marked exception falls into line when the position of the observer is properly credited with its influence on appearances.

With the examples of edge-on spirals (pl. 4) before us, imagine ourselves again within one of these objects, at some distance from the center, with our eyes turned toward the nucleus. Does it seem likely that we should then see the central condensation? Apparently not, at least not the brightest portion at the very center. Even

casual inspection of Plate 4 a, b, c, reveals the dark broken band extending the length of the images which is a conspicuous feature of almost every edge-on spiral that we know. This band consists of obscuring clouds of nebulous material, dark ordinarily, unless illuminated or stimulated to shine by some external source, and invisible, unless outlined by projection on a background of stars or luminous cloud. Photographs of spirals inclined to the line of sight suggest that these dark clouds extend well in toward the central condensation, and would blot out, in part at least, the bright central region from our imagined point of observation. The chances are, too, that above and below the dark clouds, in the general direction of the center, we might see outlying aggregations of stars, strewn nearly parallel to the plane of the nebula. The Milky Way of the nebula would then appear split for part of its length into two branches by a great rift, like that which in our own system extends from Cygnus in the north to Circinus far down in the southern heavens. We know that much obscuring material is scattered over the galactic plane among our own stars, and that the dark, almost starless region between the two branches of the Milky Way is probably a thick pall of cloud. The direction of the center of the system cuts into this cloud, and it has been suggested that but for the cloud we should see something comparable with the central condensation of the spirals. The off-sided concentration of stars which, as a central nucleus, seemed so out of harmony with the vastness and grandeur of the system, would then represent the crowding of the stars naturally to be expected toward the center, modified and ultimately suppressed by the obscuring clouds, long before the center is reached.

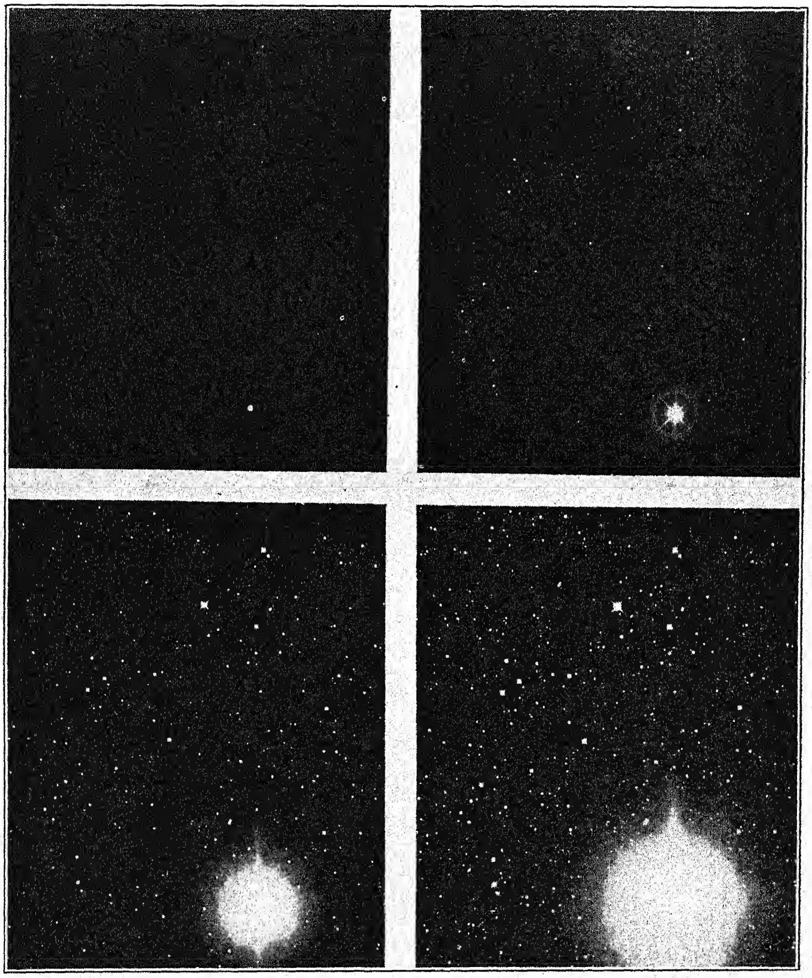
The asymmetry of distribution is further accentuated by the fact that the curve for the larger system shown in Figure 3 has been derived from counts made, not in the exact direction of the center, but in the branches of the Milky Way immediately above and below the central point. For a system perfectly symmetrical about its center, the distribution of density along lines thus inclined to the principal plane would necessarily be unsymmetrical; the maximum density would be less than at the center, and less distant than the central point. Finally, the position of the maximum may also be influenced by one of the local aggregations of stars which the Milky Way structure, as well as the appearance of the spirals, suggests as lying scattered over the galactic plane.

When invoked to explain the peculiarities of stellar distribution, the well-known analogies between spirals and our own system answer very well; but, unfortunately, they leave us still in doubt as to our exact location within the larger system. The presence of obscuring material means that star counts probably can never remove that doubt. For the present we can only accept Shapley's estimate

based on the distribution of the globular clusters, which places the center of the system at a distance of 50,000 to 60,000 light years in the direction of longitude 325°. The close agreement of the longitude with that found from star counts supports the belief that the clusters also correctly indicate the distance to the center. If the diameter of the system may be regarded as of the order of two or three hundred thousand light years, as suggested above, we should then find ourselves something like half-way out toward the edge of the system.

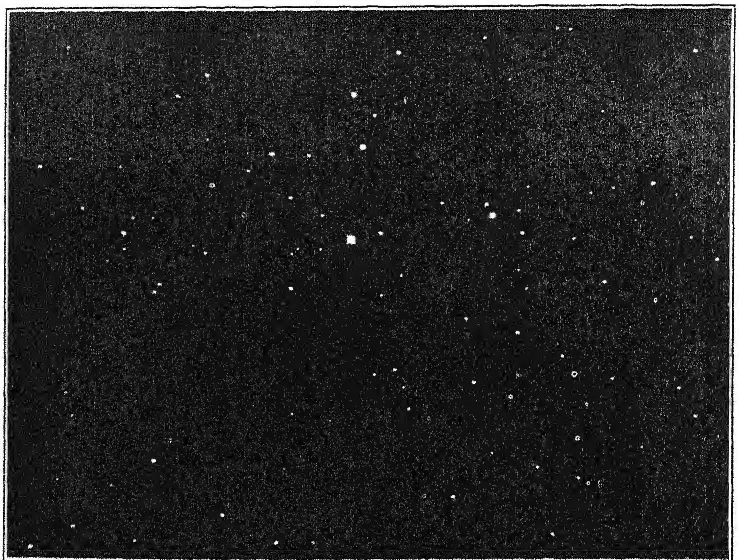
But where does the local system, which so dominates the situation about us, fit into the picture? It is, perhaps, only an exceptionally large aggregation of stars similar to those scattered along the arms of the spiral nebulæ; or it may be a more or less independent organization of stars entangled within the larger system—instances of the close juxtaposition of two spirals, for example, are not unknown; but perhaps the only safe conclusion at present is that a local system of unexpected richness and size exists. The members of this system are numerous enough to impress something of their own characteristics on the distribution of the stars as a whole down to a low limit of brightness, and are therefore certainly to be counted by millions. In so large a collection it is natural to expect stellar luminosities and spectral types similar to those in the larger systems. This being the case, the surprisingly large dimensions found for the local system follow as a matter of course.

In closing, a word of caution is to be added: The picture drawn of the stellar system is only a sketch in broad outlines. Conclusions based solely on star counts may be regarded as reliable, for it is probable that the counts rest on a sound photometric system; structural features derived from analogies with spiral nebulæ are less certain but still probable; estimates of dimensions and distances are uncertain, and, in some instances, possibly not even of the right order of magnitude. Above all, it must not be forgotten that practically all the conclusions formulated depend on a study of but two characteristics of the stars—the numbers seen in different directions in the sky and the totals down to different limits of brightness. This restriction accounts in part for the lack of detail in the picture; at the same time it may mean that results which now seem well established will require modification and readjustment when other stellar characteristics have been intensively studied.



PHOTOGRAPHS WITH INCREASING LENGTH OF EXPOSURE OF A SMALL FIELD ABOUT η AURIGAE

Illustrating the rapid increase in numbers of stars with decreasing brightness. The faintest stars shown are approximately of the twelfth, fifteenth, eighteenth, and twentieth magnitude.



1

2

1. SELECTED AREA 56, 80° DISTANT FROM THE MILKY WAY
2. SELECTED AREA 40, IN THE MILKY WAY ITSELF

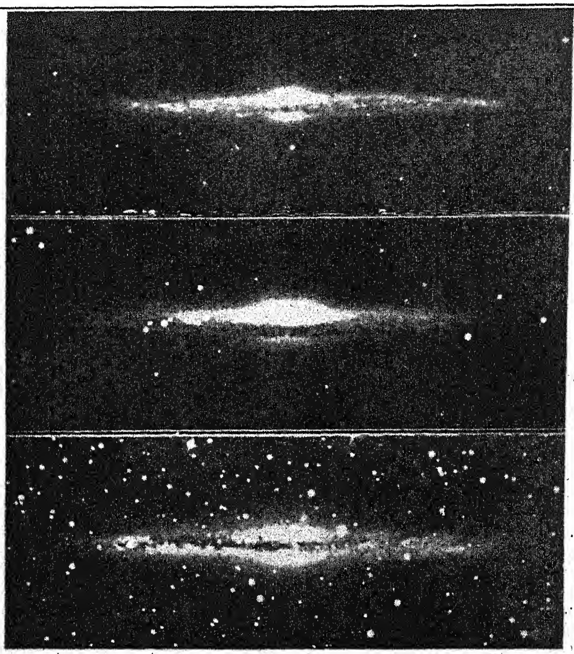
Photographs of two fields of the same size, both showing stars to the eighteenth magnitude. The photographs illustrate the great concentration of faint stars in low galactic latitudes.

1

2

1. MESSIER 101 IN URSA MAJOR
2. MESSIER 33 IN TRIANGULUM

Examples of spiral nebulae seen broadside; photographed with the 60-inch reflector. Both nebulae are well resolved into stars and show dark clouds of obscuring material intermingled with the stars and with clouds of luminous nebulosity.



a

b

c

1

2

1. TYPICAL SPIRAL NEBULAE SEEN EDGE ON

a, HV 24 Comae Berenices; *b*, N. G. C. 5746, Virgo; *c*, HV 19 Andromedae; photographed with the 60-inch reflector. In outline the nebulae resemble the flattened watch-shaped form of our own system. Dark obscuring clouds lying close to the central plane of the nebulae are conspicuous in each.

2. OUTLYING REGIONS OF M 31, PHOTOGRAPHED BY HUBBLE WITH THE 100-INCH REFLECTOR

Parts of the nebula which on smaller-scale photographs appear as knots or condensations are here fully resolved into stars.

THE LINGERING DRYAD[1]

By Paul R. Heyl

U. S. Bureau of Standards

There is an every day test which we all instinctively apply when we are in doubt whether a certain thing is alive. We watch for it to move. This is a test as old as humanity, though as we now apply it we introduce a logical refinement which was lacking in other days. Absence of motion, now as then, indicates absence of life, but the mere observation of motion does not always suggest to modern thought the presence of life. A sheet of paper may be rustled by an invisible breeze; stormy waves may arise in the ocean; the ground beneath our feet may tremble and split open; yet we of to-day see in such phenomena no reason for assuming life as a cause.

Not so with the ancients. To them motion invariably suggested life, directly or indirectly involved. The sheet of paper, of course, was not alive, but the wind was the breath of Æolus. The stormy sea was the direct physical result of the wrathful strokes of Neptune's trident, and the heaving earth, by the same token, gave evidence of the displeasure of Poseidon, the earth-shaker.

While the mythology of the ancients contained much that we now regard as childish and ridiculous, there is also to be found in it that which we must still recognize as beautiful, such as the myth of the dryad.

The dryad was a tree nymph. Every tree had its protecting spirit who was born with the tree, lived in or near it in intimate association, watching over its growth, and who died when the tree fell. The dryad was thus a personification of the life of the tree, and the connection between nymph and tree was far more intimate than was the case with the deities dominating sea or wind. Because of this peculiarly intimate relation the tree possessed life which the sea did not, though Neptune inhabited its depths, and which the wind did not, though set in motion by Æolus.

The men of old, it seems drew very much the same distinction that we do when we speak of living and nonliving substances. Water,

[1] Presidential Address before the Philosophical Society of Washington, Jan. 5, 1929. Reprinted by permission from Journal of the Washington Academy of Sciences, vol. 19, No. 4, Feb. 19, 1929.

they observed, never grew old or died, but a tree was obviously a living thing, almost one of us, growing, reproducing its kind, and eventually dying. And as the ancients had difficulty in forming an idea of life without an animating personality there arose naturally the concept of the inseparable tree nymph.

Human thinking from the first has been frankly anthropomorphic. Only in modern times has there been any notable effort to cast out anthropomorphism from our philosophy, and this struggle has not yet resulted in victory. Even we of to-day, with hereditary habits of thought heavy upon us, find the concept of impersonal, physical causes drab and unsatisfying, and we spell Nature with a capital N. The dryad lingers.

In the chemistry of other days we find an interesting case of the persistence of this mode of thought. The old alchemists knew that wine by boiling lost its intoxicating power. Because they could see nothing escaping they said that the "spirit of wine" had found its abode too hot for it, and had taken its departure. Cassio used no figure of speech when he apostrophized the "invisible spirit of wine" by which he had been so disastrously possessed of the devil, and the name "spirit" as applied to alcohol is still in common use.

With the advance of knowledge it was found that many other phenomena beside intoxication owed their causes, not to spirits or devils, but to inanimate, prosaic chemical compounds. So strong, however, is heredity that the dryad, instead of disappearing from human thinking, merely changed her form and retreated under fire to a position of advantage across a natural barrier, where she long remained in safety.

It was many years before this barrier was crossed. The dividing line between organic and inorganic substances was a sharp one in the eighteenth century, and from her safe refuge in the domain of organic chemistry the dryad long watched her baffled foes. The older chemists divided the province of their science in two by a water-tight partition. All compounds with which they were acquainted could be analyzed or broken down into their elements, but not all of them could be built up again by human skill. Water might be formed from its constituents, but not sugar or starch; yet these latter substances were daily synthesized in the laboratory of Nature, in the tissues of animal or vegetable matter; and because they were never known to occur in mineral or inorganic matter, substances of this type were called from their origin, organic compounds.

Years of experience had given rise to the belief that there existed between these two classes of bodies a difference in kind rather than in degree, and that there was some reason not understood why organic compounds could not be synthesized artifically. This unknown reason was given a name; it was called the "vital force."

It often happens that when the unknown is named it appears as if it were more than half explained. The vital force once named soon came to be a familiar concept. It was held to be resident in living matter, whether animal or vegetable, much like the dryad in the tree. It was believed to differ in kind from the chemical and physical forces that governed the formation of inorganic compounds. Under the influence of this vital force it was believed that all the chemical reactions of living matter took place, and it was even supposed to govern the decompositions that occurred after death.

The belief in a vital force of this nature was universal among eighteenth century chemists, even Berzelius being found among its adherents. The vital force seems to have been regarded with something like the awe inspired by the supernatural, and it was well into the nineteenth century before its hold on men's minds began to relax.

The past year, 1928, marked the century of an epoch in human thought, for it was just 100 years since the doctrine of a vital force received its logical death blow. In 1828 Wöhler succeeded in producing by laboratory methods the first organic compound. This was urea, which he prepared by simply heating an inorganic compound, ammonium cyanate, containing the same elements as urea, namely carbon, hydrogen, oxygen, and nitrogen, and in the same proportions.

This was a body blow at the dryad, but she died hard. Her devoted adherents rallied to her support and explained away Wöhler's result in various fashions. In this they were aided by the fact that for years this synthesis stood alone, suggesting that there was something exceptional about it. Some said that this proved merely that a mistake had been made; that urea was not really an organic substance, but occupied a place halfway between the organic and inorganic kingdoms. Others argued curiously that the carbon of the cyanate retained some trace or memory of the vital force which had ruled it when it had previously been a part of some organic compound. But in time other syntheses were achieved in such numbers that the accumulated evidence became overwhelming, and it was finally recognized that organic chemistry was only complicated inorganic chemistry, and that the difference between the two was one not of kind, but of degree of complexity.

We have said that the dryad died hard. As a matter of fact she did not die at all—she emigrated. Dispossessed by the advancing frontier of knowledge from the domain of organic chemistry which had so long afforded her a refuge, she retreated under fire into a less understood region beyond—into the biological sciences. Here the complexity of phenomena was (and still is) so great that among the shadows the dryad still finds a retreat.

Biologists of to-day are divided into two camps—vitalists and mechanists. Between them a conflict rages, and the fate of the dryad still hangs in the balance. The vitalists argue that whatever may

have been the case in the past we have now, by the progress of our knowledge reached a dividing line which really marks a difference in kind; that there have been brought to light in the realm of biology phenomena of such a nature that they are not explainable by ordinary chemical or physical principles; that it is necessary to assume a principle peculiar to living matter (in other words, a "vital force") to explain them. Let us select what is perhaps an extreme case in illustration.

Food taken into the stomach of man and other animals is digested by means of the gastric juice. Some of this food is meat (all of it in the case of certain animals), muscular tissue like that of the stomach itself. The question naturally arises why the gastric juice does not digest also the wall of the stomach. Is it not like trying to dissolve a piece of zinc in acid contained in a zinc vessel?

It is not easy to answer this question. It can not be due in any way to mastication, for if a piece of meat is swallowed without chewing, the stomach will eventually digest it. It can not be argued that cooking accounts for the difference, for this is an art practiced by man alone, and is a comparatively late acquisition on his part. And in the face of the use of tripe as an article of food it can not be that the stomach contains a protective substance which other muscular tissue does not possess.

There seems to be no difference between the stomach and the food other than that the stomach is alive and the food dead, whatever this may mean; and even this explanation is hard pushed by the fact that the food of carnivorous animals under natural conditions usually reaches the stomach of the captor in a very short time after the death of the prey, an interval measurable almost in seconds.

By considerations such as these the controversy between the vitalist and the mechanist is kept alive. The vitalist maintains that between the phenomena of the living and the nonliving there is a difference in kind, not merely in degree. Just what this difference may be he is not prepared to say, but he maintains its existence. The mechanist, on the other hand, says that exactly the same arguments have been advanced in the past in connection with problems that seemed just as insoluble, and that these arguments have finally been disposed of by the progress of our knowledge. Differences in kind, once regarded as numerous in Nature, have slowly and steadily been resolved into differences in degree. Sharp lines of demarcation have been wiped out until the line between the living and the nonliving is perhaps the only one left. Such diverse phenomena as those of electricity and light have been found to be closely akin; man himself has been shown to be one with the rest of animated Nature; and if the past is any guide to the future, it seems that even this last sharp line will some day disappear also.

Perhaps the vitalist himself may not realize it, but to the student of the philosophy of history this vague "difference in kind" suggests the last lingering trace of what was once a dryad. As a cloudlet dwindles and disappears in the beams of the sun, so the dryad has shrunk to a mere wisp of vapor, which with a little more light seems destined to disappear forever.

But now that we have finished pointing out the mote that is in the biologist's eye, let us examine our own clarity of vision. Are we physical scientists in any measure responsible for the lingering of the dryad?

By the latter half of the nineteenth century physical theory had become a well knit, sharply crystallized and self-sufficient body of doctrine. While it was recognized fully and generally that much was as yet unknown, it was felt quite as generally that what had been established would, with perhaps a little amendment and modification, stand forever. The physical theory of the last century was much admired by its devotees, upon whom it reacted in turn to the extent of making them at times a bit dogmatic. If there was a conflict between physics and a sister science, physics must be right.

The classical instance of this attitude is the famous controversy over the age of the earth, between the physicists on the one hand and the geologists and biologists on the other. Perhaps nothing in the annals of nineteenth century physics made such an impression upon the sister sciences. This controversy lasted for 33 years with unabated vigor, and was not finally settled until the discovery of radioactive substances.

In 1862, upon the basis of the laws of the conduction of heat as laid down by Fourier, Kelvin calculated that the time that had elapsed since the earth had solidified from a molten state could not be less than 20,000,000 or more than 400,000,000 years. He admitted that rather wide limits were necessary, but was inclined to attach more weight to the lower figure than to the higher. In this he was confirmed by a similar calculation made by Helmholtz of the age of the sun.

At this estimate biologists and geologists stood aghast. The prospect of having to pack into a paltry 400,000,000 years the whole progress of organic evolution from amœba to man seemed to biologists unreasonable. And with the geologists the situation was still worse. It was generally recognized that a very long period of time must have elapsed after solidification before life of the most primitive form made its appearance, and this period, in addition to that required by evolution, must be made to fit Kelvin's Procrustean bed. Moreover, it was felt by geologists that such a view involved a return to eighteenth century ideas, from which geology was just beginning to emerge.

Prior to the nineteenth century geological thought was of the catastrophic school. It was held that natural forces were more active and powerful in past geological ages than they now are; that great convulsions of Nature had riven the crust asunder into valleys and elevated other portions into mountains. By the middle of the nineteenth century the opposte, or uniformitarian school of thought had achieved the ascendency, largely through the influence of the geologist Lyell. On this view it was held that geological processes had never differed seriously from those of the present day. As a consequence of this doctrine an immense antiquity was required for the earliest geological strata, and with this almost unlimited time at their disposal biologists felt unhampered.

Then came Kelvin's bombshell. Protest and appeal were not lacking, but Kelvin was inexorable. Physics, he said, could grant no more, and physics held the power of the purse of time.

The widespread and long-continued interest in this controversy is evidenced by the many letters published on the subject in "Nature" from January to April, 1895. As proof of the fact that Kelvin did not stand alone in this matter it is of interest to note that not a single physicist failed to support him in theory, though there was a general feeling that perhaps his limits might be widened somewhat. The discussion was finally summed up by its initiator, Prof. John Perry, who expressed the opinion that the upper limit assigned by Kelvin might perhaps be multiplied by four. But this concession brought about no rapprochement. The two sides were not near enough to dicker.

A few years later the deadlock was finally resolved by the discovery of radioactivity. This new and totally unexpected source of terrestrial heat nullified Kelvin's fundamental postulate, and allowed as much time as the most extreme views could require.

Rightly or wrongly, this celebrated case had an unfortunate effect upon interscientific relations. The biologists in particular felt that the character of their problems and the evidence for their conclusions were not appreciated by the physicists. The impression was gained that physics was for some reason incompetent to treat of biological questions, and that the life sciences required for their complete discussion and development something that was not and could not be found in physical theory. It may scarcely be doubted, I think, that this impression of the inadequacy of physics went far toward strengthening and prolonging the life of the vitalistic hypothesis.

But, to be fair, we must recognize that the vitalism of to-day is not that of a century ago. To use a term borrowed from mineralogy, it is but a pseudomorph of its predecessor, cast in the mold of the older form and simulating its outward shape, but inwardly of a different composition. The neovitalist of to-day disclaims utterly anything

savoring of the occult or the supernatural; short of this, he is ready to accept any adequate explanation of life. He maintains, however, with equal firmness that even modern physical theory lacks something necessary to explain vital phenomena; that no interplay of atoms, however complicated, can account for the simplest manifestation of life. In brief, the vitalist looks outward for the explanation of life; the mechanist looks inward.

The attitude of the mechanist is, for the present, largely one of faith and hope rather than sight. He admits that modern physical theory affords no explanation of life, and that there is no reason to believe we are any nearer a solution now than we were a century ago. But, encouraged by precedent, he holds steadily his faith that some new and unexpected discovery may at any time clear our vision as radioactivity clarified that of our predecessors. And he is confident that when the solution of this mystery is reached it will be found to be internal rather than external.

But while we are waiting for something of this kind to happen, may we by any chance find some foreshadowing of a possible common ground in existing physical theory?

Let us imagine, if we can, some one whose physical experience has been limited to solids and who is ignorant of molecules and atoms. The latter will not be so difficult when we remember that it has not been so very long ago that we were all ignorant of any subatomic structure. Matter, to our supposed observer, is continuous and infinitely divisible without alteration in its properties; its structure is perfectly uniform to the last conceivable degree. Suppose further that he observes for the first time the melting of a solid. That which would probably impress him most in this process would be its abruptness, its sharp initiation. By continual influx of heat the solid suffers a steady rise of temperature, which seems as though it might continue indefinitely as long as heat is supplied. But suddenly, without warning or apparent cause, a critical point is reached. Though the influx of heat is not halted the temperature stops rising. A new effect is seen, different in kind from any phenomenon known in solids. We say that the body is undergoing a change of state and is becoming a liquid. In this new state new laws govern its behavior; new properties are evident, differing in kind, not in degree, from those of solids.

Our unsophisticated observer might well wonder at this curious behavior; but should we, from our superior knowledge attempt to tell him that this difference in appearance and behavior is not a matter of composition or outside forces, but of internal structure, we might find him rather incredulous.

"No," he might say. "Something has happened to stop the rise of temperature. There has been an introduction of a new factor into the situation. You speak of structural difference. I do not under-

stand you. The structure of a solid, as I am familiar with it, could not be more simple than it is—continuous, infinitely divisible, uniform throughout, with no shade of difference anywhere upon which to build up an explanation. No; we must look outside for the cause of this change. Liquid phenomena are not expressible in terms of the properties of solids. He who maintains that they are is a mechanist."

In this belief he might be confirmed if he pushed the heating of the liquid far enough. At a second critical point, again unheralded and without apparent reason, the liquid begins to boil, and the resulting gas exhibits a new set of phenomena, differing in kind from anything to be found in either solids or liquids. The new phenomena in this case depart even more widely from those of the other states than was the case at the first critical point.

To us, with our knowledge of molecules, the explanation of these critical points and different states is comparatively simple and internal. It is true that the phenomena of one state are not to be expressed in terms of the properties of another; the behavior of gases can not be deduced from the laws of elastic solids or of incompressible liquids. The solution does not lie in a line joining one state to another, but goes back from each state to the common basis of molecular structure underlying all states, something of which our observer is yet to become aware. And until a similar common ground for the phenomena of living and nonliving matter is recognized there must be a difference of opinion between the vitalist and the mechanist.

What this common basis may be we can not as yet surmise. It remains for some new discovery to open our eyes. It must be something deeper and more fundamental than molecules or atoms. In so far the vitalist is right; and in so far as he maintains that the mere interplay of atoms contains the key to the mystery, the mechanist is wrong. But such a common basis, underlying and forming part of nonliving as well as living matter, would be an internal factor, and it is for such a factor that the mechanist is looking.

The parallel here suggested is worth pushing farther. The past history of Nature has been one of change, of growth, of that development which we call evolution. Her future, if hindsight is to be trusted, will carry this evolution onward to a consummation of which we can as yet form no conception. Nature, we may say, has been steadily warming up to her work since the beginning of things. And in this warming up process we may distinguish several critical stages, strangely suggestive of the different states of matter.

The first of these critical points was reached millions of years ago, when life first made its appearance, a totally new phenomenon superimposed upon inanimate Nature. For untold ages life was impossible on the earth, but eventually, when conditions allowed, life appeared, no one knows how. With its appearance a new order of things was

introduced, and phenomena not to be found in inorganic Nature began to show themselves. With the advent of the organic, new motives of action are recognizable, and new combinations are possible. The vitalist explains this by bringing in a mysterious something from the outside; the mechanist is persuaded that matter in acquiring life has not ceased to be a conservative system; only in its behavior is it transformed.

Moreover, this transformation has not been complete. Living and nonliving matter exist side by side and will probably continue to do so. The physicist would call this the coexistence of two phases at one temperature, like a mixture of ice and water at the freezing point, each following its own laws and exhibiting its own characteristic properties under the same environment.

We may, perhaps, by poetic license think of the first beginnings of life as feeling strange and lonely in the midst of the nonliving matter surrounding them, so different in properties, in behavior. And perhaps we may imagine that the works and ways of nonliving matter occasionally grated on the sensibilities of the living, and called forth the protest: "Why are you so mechanical? Why not show a little flexibility occasionally?" But this protest, we may imagine, was wasted. "It is my ancient way," replied nonliving Nature. "the way I did for millions of years before you newcomers appeared upon the scene. I can not mend my case. Why not do as I do and be sociable?"

But this is just what living matter will not do. Like white men in the Tropics, it maintains its standard of living among an overwhelming majority of an inferior grade of civilization.

Millions of years have passed. Life is no longer a newcomer, a feeble colony, but has waxed mighty, and has become the outstanding feature of the earth's surface. And now we have reached a second critical point. Life has attained such a degree of complexity that a new set of phenomena is beginning to make its appearance, something different in kind from anything that has been before; as different in its turn as was life itself compared to inanimate matter; something superimposed upon life as life of old was superimposed upon the nonliving. And it is, appropriately enough, in man, the highest type of life, the flower of creation, the peak of evolution, "the heir of all the ages in the foremost rank of time," that this new thing first makes itself manifest—a moral sense, an ethical feeling, which often finds itself as much a stranger in its environment as life must have felt among the crystals and colloids among which it began its existence. If we must find a single word to express this new quality let us call it "Soul."

Within us is developing a new thing, as wonderful as life itself and no less rich in possibilities. Life in its turn has brought forth some-

thing of a higher order, transcending itself, as it once transcended nonliving matter. And that this new thing has elected to make its appearance in and through us, the highest of Nature's children, what is more reasonable? Do men gather figs of thistles?

But here the vitalist takes his last stand. "I know," says he, "that past history points your way; that one step after another, I have been forced to give ground. I, who once held that no one but God could make an organic compound, have lived to see it done by high-school students. You mechanists, on the other hand, have pressed steadily forward. But beware lest, flushed with success and intoxicated with power, you attempt too much and achieve your own downfall. What you tell me now goes beyond all bounds of credence. Am I to understand that all that makes a man, his ethics, his poetry, his music, his aspirations, his ideals, are from within? Are these, too, of the earth, earthy? Never! These, at last, must come from without. Can ideals rise higher than their source?"

Of the earth, earthy! But why should there be anything mean or unworthy about that which comes from within rather than from without? Is the macrocosm essentially nobler than the microcosm?

True, tradition runs that way. Man at different times has set his gods in the most inaccessible places, on the summit of Mount Olympus, or across the rainbow bridge in Asgard; but the greatest idealist that our race has produced broke with this tradition when he said: "The kingdom of God is within you."

And perhaps it may be true that ideals can rise higher than their apparent source. Just as every great genius had parents of less than his own ability, who yet in some mysterious way endowed him with more than they themselves possessed, so Nature has produced within us something without precedent in the life history of the earth. And as a parent watches with pride a child who gives early promise of outdistancing his elders, so Mother Nature may be watching us.

What is this new thing which Nature has brought forth, and with the development of which we have been intrusted? No man can say, but it is a fair inference that it will go far. Life has gone far from a tiny speck of protoplasm; who knows to what lengths this new thing, this mind, this soul, if you will, may carry us? For it doth not yet appear what we shall be.

WHAT IS LIGHT?

By Arthur H. Compton

[With 5 plates]

As long ago as the seventeenth century, Newton defended the view that light consists of streams of little particles, shot with tremendous speed from a candle or the sun or any other source of light. At the dawn of the nineteenth century, however, experiments were performed which were thought to give positive evidence that light consists of waves. Maxwell interpreted them as electromagnetic waves, and in such terms we have ever since been explaining light rays, X rays, and radio rays. We have measured the length of the waves, their frequency and other characteristics, and have felt that we know them intimately. Recently, however, a group of electrical effects of light has been discovered for which the idea of light waves suggests no explanation, but whose interpretation is obvious according to a modified form of Newton's old theory of light projectiles.

REVIEW OF THE VARIOUS ELECTROMAGNETIC RADIATIONS

When the physicist speaks of light he thinks not only of those radiations which affect the eye. He refers rather to a wide range of radiations, similar to visible light in essential nature, but differing in the quality described variously by the terms color, wave length, or frequency.

At one end of this series of radiations are the wireless, or radio rays, with which in recent years we have become so familiar.

Measured in terms of the length of a wave, electric waves extend from many miles in length down through the radio waves of say 300 meters, to the very short waves resulting from tiny sparks, which may be no more than a tenth of a millimeter in length. These rays overlap in wave length the longest heat waves radiated by hot bodies, and may be detected and measured by the same instruments. A familiar source of such heat rays is the reflector type of electric heater, the kind that warms one side of us in a chilly room. The greater part of these heat rays are intermediate in wave length between the shortest electric waves and visible light. Such a heater, however, glows a dull red, showing that its rays extend into the visible region.

Ordinary visible light is well represented by the radiation from a carbon arc. If its rays are passed through a prism, they are spread into a spectrum of many colors, from red to violet, which the prism has separated from each other. Beyond the red end of the spectrum lie the heat rays. Indeed if we should place a radiometer just beyond the red end of the spectrum, we should find it strongly affected by the heat rays from the arc. The question arises, are there similar radiations beyond the violet which we are unable to see?

If a fluorescent screen of platinum barium cyanide is brought up, we notice a brilliant green glow extending far beyond the violet light visible on the ordinary screen. Evidently our failure to see light in this region is not because there is no light, but because our eyes are insensitive to rays of this type. The fluorescent screen changes their color so that we can see them. These are the ultra-violet rays, of

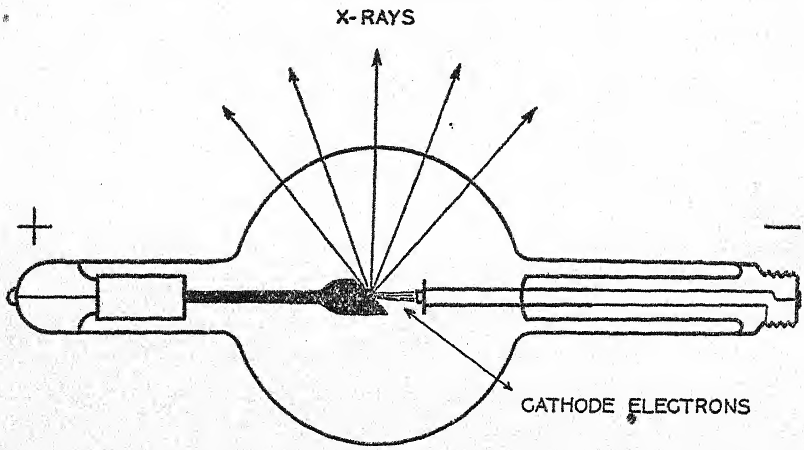


FIGURE 1.—Coolidge X-ray tube. Electrons shot from the cathode against the target produce these X rays, which are light of very short wave length

which we have heard so much recently in connection with summer sunshine and prevention of rickets.

As one goes farther into the ultra-violet the rays become rapidly absorbed by air, and can be studied only in a vacuum. But at still shorter wave lengths the rays are again less readily absorbed as we approach the region of X rays. A high-tension transformer shoots the electrons at high speed from the hot wire cathode against the tungsten target and there X rays are emitted (fig. 1). It is like shooting a rapid-fire gun at a steel plate. The bullets represent the electrons shot from the cathode, and the noise resulting when the bullets bang against the plate represents the X rays.

Just as in the case of ultra-violet light, these X rays do not affect our eyes. Their existence can, however, be shown by placing in their path the same screen as was used to detect the ultra-violet rays.

That these rays are of the same nature as light is shown by the fact that we have found it possible to reflect and refract them, to polarize and diffract them. They are indeed light of ten thousand times shorter wave length.

One of the most important properties of X rays is their ability to ionize air and make it electrically conducting. Such ionization can also be produced by the gamma rays from radium. Whereas, however, X rays may be half absorbed in an inch of water, it takes a foot of water to absorb half of the gamma rays from radium, corresponding to the much shorter wave length of the radioactive rays.

But the end is not yet. There exists a kind of highly penetrating radiation which is especially prominent at high altitudes, and is supposed to come from some source outside the earth. These *cosmic rays*, as they are called, will penetrate 10 or 20 feet of water before they are

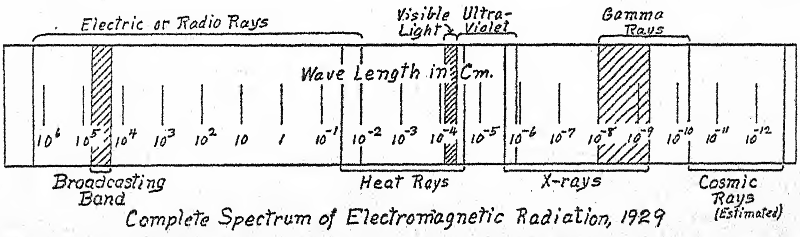


FIGURE 2.—Complete spectrum of electromagnetic radiation on a logarithmic scale. Visible light is only a small but very important part of this spectrum

half absorbed. It is possible that these rays are like cathode rays, rather than X rays, though they are usually thought to be of the latter type.

In Figure 2 we see graphically how these different rays are related to each other. At the extreme left I have arbitrarily started the spectrum at a wave length of 18 kilometers, which is the wave length of certain trans-Atlantic wireless signals. There is no reason why longer waves could not be produced if desired. The electric waves continue in an unbroken spectrum down to 0.1 mm., rays recently studied at Cleveland by the late Doctor Nichols and Mr. Tear. Overlapping these electric rays are the heat waves, which have been observed from about 0.03 cm. to 0.00003 cm., including the whole of the visible region. The heat rays in turn are overlapped by the ultraviolet rays, produced by electric discharges; and these reach well into the region described as X rays. Beyond these are in turn the gamma rays and the cosmic rays. Thus over a range of wave lengths of from 2×10^{-13} cm. to 2×10^{6} cm. there is found to be a continuous spectrum of radiations, of which visible light occupies only a very narrow band.

The great breadth of this wave-length range will perhaps be better appreciated if we expand the scale until the wave of a cosmic ray has a length equal to the thickness of a post card. The longest wireless wave would on this scale extend from here to the nearest fixed star.

When the physicist speaks of light, he refers to all the radiations included in this vast range. We believe that they are all the same kind of thing, and that anything which may be said about the nature of the rays in one part of this region is equally true of the rest.

LIGHT CONSISTS OF WAVES

There are many ways in which light acts like a wave in an elastic medium. Such elastic waves move with a speed which is the same for all wave lengths and all intensities, just as does light. Waves, like light rays, can be reflected and refracted. The polarization of light is a property characteristic of the transverse waves in an elastic solid. It is true that if one examines the constancy of the speed of light in detail, difficulties arise; for it is found that its speed is the same relative to an observer no matter how fast the observer is going. This would not be true if light were a wave in an ordinary elastic medium. Maxwell's identification of light as electromagnetic waves, however, removes this difficulty.

The crucial test for the existence of waves, however, has always been that of diffraction and interference. Imagine a row of pebbles dropped into a pond at the same instant. The effect would be similar to that shown in Plate 1, Figure 1. In this figure we picture a series of waves passing through a succession of openings in a grid. After passing through, the crests of the emerging wavelets recombine to form a new wave going straight ahead. But in addition, the wavelet just emerging from one opening may combine with the first wave from the next opening, the second from the next, and so on, forming a new wave front inclined at a definite angle to the first. The angle between these two waves, as will be seen from this diagram, is determined by the distance between successive waves, i. e., the wave length, and by the distance between successive openings in the grid. The figure at the right shows how the emergent wave may combine with the second wave from the adjacent opening, the fourth from the second opening, and so on, and form a wave front propagated at a larger angle.

That such a variety of wave formation is not purely imaginary is shown in Plate 1, Figure 2, which is a photograph of ripples on the surface of mercury, taken after they have passed through a comblike grid. Notice how one group of waves combines to form a wave front going straight ahead. But in addition, on either side of the central beam, we find two beams forming where the paths from successive openings in the grid differ by one wave length. Out at a large angle we see even the second order of the diffracted beam.

If we were unable to see the separate waves, but knew the kind of grid through which the beam of ripples had passed, not only could we say that this is the way the beam should be split up if it consists of waves, but we could even tell what the wave length of the ripples must be in order to give these particular angles between the diffracted beams.

The same experiment may be performed with a beam of light. In Plate 2, Figure 1, is shown a set of some 200 vertical lines. If these lines are photographed onto a lantern slide, they form a grid through which a beam of light may be made to pass. The upper part of Plate 2, Figure 2, shows a beam of light projected onto a photographic plate. The middle part of the figure shows the same beam of light, but this time projected through such a lantern slide grid having about 100 lines to the inch. The original spot of light is now split into three, a bright one in the center, the direct ray, and a diffracted ray on either side. It is just as in the case of the mercury ripples passing through the grid.

If this is really a case of the diffraction of waves, as we have supposed, if a grating with lines closer together is used, the separation between the diffracted images should be correspondingly greater. The lower part of Plate 2, Figure 2, shows our beam of light projected this time through a grid photographed with about 300 lines to the inch. The separation of the diffracted beams is now much greater.

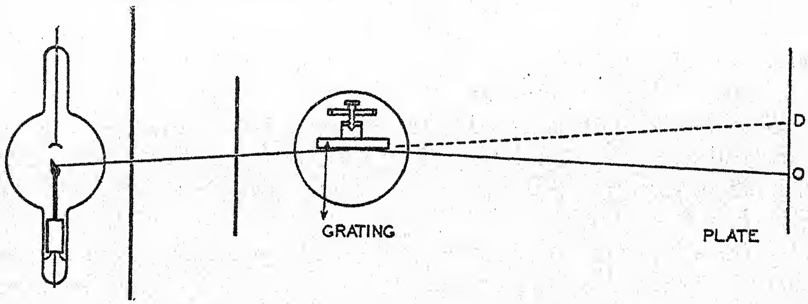


FIGURE 3.—Apparatus for diffracting X rays from a ruled reflection grating

When these diffracted images are thrown on a screen, one can see that their outer edges are red and their inner edges blue. This means that red light is of the greater wave length. In fact we could easily, from this experiment, tell what the wave length of light is—the distance from the central image to the diffracted image is to the distance from the grating to the screen as the wave length of the light is to the distance between the lines on the grating. When one carries through the calculation, he finds that the wave length of light is about one fifty-thousandth of an inch.

If we can rely on such a test, light must consist of waves.

Diffraction of X rays.—Precisely similar experiments can, however, be done with X rays. In place of a projection lantern we must, however, use an X-ray tube and a pair of slits as shown in Figure 3. The lantern slide with the lines on it is replaced by a polished mirror on which lines are ruled 50 to the millimeter. The resulting photograph is shown in Plate 2, Figure 3. When the ruled mirror is with-

drawn we have the single vertical line D. With the grating in place we see a bright central reflected image O with companions on either side. Thus X rays can also be diffracted, and must therefore, like light, consist of waves.

LIGHT CONSISTS OF PARTICLES

For a hundred years no one had seriously questioned the truth of the wave theory. In 1900, however, Planck published the results of a long study of the problem of the radiation of heat and light from a hot body. This difficult theoretical study, which has stood the test of time, showed that if a body when heated is to become first red hot, then yellow, and then white, the oscillators in it which are giving out the radiation must not radiate continuously as the electromagnetic theory would demand. They must rather radiate suddenly little portions of energy. The amount of energy in each portion must further, according to Planck, be proportional to the frequency. This is the origin of the celebrated "quantum" theory.

On account of the difficult character of the reasoning involved in Planck's argument, his conclusions carried weight only among those who were especially interested in theoretical physics. Among these was Einstein, who called attention to the fact that Planck's conclusions would fit exactly with the view that the radiation was not emitted in waves at all, but as little particles, each possessing a portion of energy proportional to the frequency of the oscillator, as Planck had assumed.

Einstein and the photoelectric effect.—An opportunity to apply this idea was afforded by the photoelectric effect. It is found that when light, as from an arc, falls upon certain metals, such as zinc or sodium, a current of negative electricity in the form of electrons escapes from the metallic surface. This photoelectric effect is especially prominent with X rays, for these rays eject electrons from all sorts of substances. In Plate 3, Figure 1, is shown one of C. T. R. Wilson's photographs of the trails left by electrons ejected by X rays passing through air and a sheet of copper. These electrons, shot out of the air and the metal by the action of the X rays, are the X-ray photoelectrons.

The most remarkable property of these photoelectrons is the speed at which they move. We have seen, as in Figure 4, that X rays are the waves produced when the cathode electrons bombard a metal target inside the X-ray tube. Let us suppose that a cathode electron strikes the target at a speed of a hundred thousand miles a second (they move tremendously fast). The resulting X ray, after passing through the walls of the X-ray tube and perhaps a block of wood, may eject a photoelectron from a metal plate placed on the far side. The speed of this photoelectron is then found to be almost as great as that of the original cathode electron.

The surprising nature of this phenomenon may be illustrated by considering a similar event with water waves. Imagine two diving boards on opposite sides of a wide pond. A boy dives from one board into the water with a splash which sends ripples out over the pool. By the time they reach the second boy, who is swimming in the water beside the other diving board some distance away, these ripples are much too small to notice. We should be greatly surprised if these insignificant ripples should lift the second swimmer bodily from the water and set him on his diving board.

If, however, it is impossible for a water ripple to do such a thing it is just as impossible for an ether ripple, sent out when an electron dives

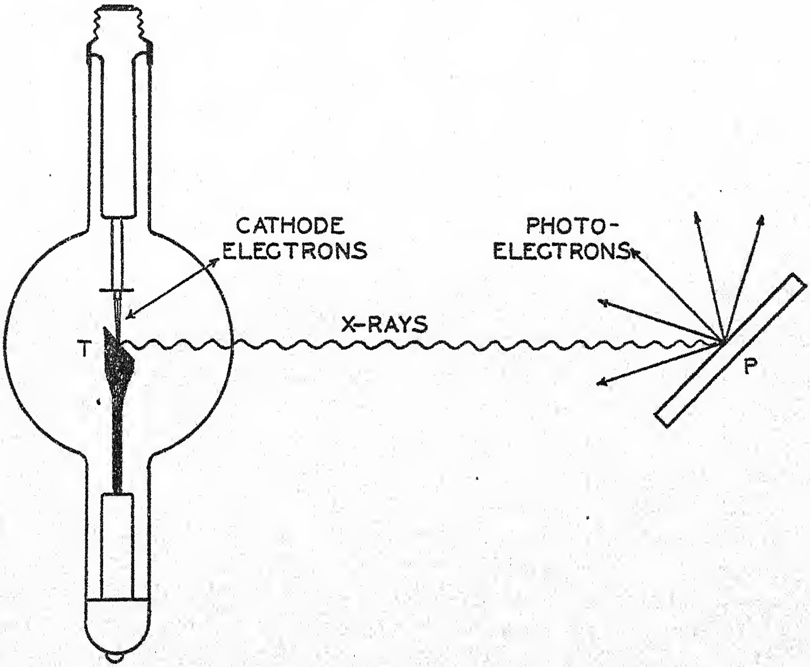


FIGURE 4.—The speed of the photoelectrons ejected from the metal plate at P is almost as great as the speed of the cathode electrons which produce the X rays at the target T

into the target of an X-ray tube, to jerk an electron out of a second piece of metal with a speed equal to that of the first electron.

It was considerations of this kind which showed to Einstein the futility of trying to account for the photoelectric effect on the basis of waves. He saw, however, that this effect might be explained if light and X rays consist of particles. These particles are now commonly called "photons." The picture of the X-ray experiment on this view would be that when the electron strikes the target of an X-ray tube, its energy of motion is transformed into a photon, that is, a particle of X rays which goes with the speed of light to the second piece

of metal. Here the photon gives up its energy to one of the electrons of which the metal is composed, and throws it out with an energy of motion equal to that of the first electron.

In this way Einstein was able to account in a very satisfactory way for the phenomenon of the ejection of electrons by light and X rays.

How X rays are scattered.—Even more direct evidence that light consists of particles has come from a study of scattered X rays. If a piece of paper is held in the light of a lamp, the paper scatters light from the lamp into our eyes. In the same way, if the lamp were an X-ray tube, the paper would scatter X rays into our eyes. If light and X rays are waves, scattered X rays are like an echo. When one whistles in front of a wall, the echo comes back with the same pitch as the original sound. This must be so, for each wave of the sound is reflected from the wall, as many waves return as strike, and the frequency or pitch of the echoed wave is the same as that of the original wave. In the case of scattered X rays, the echo should similarly be thrown back by the electrons in the scattering material, and should likewise have the same pitch or frequency as the incident rays.

We can measure the pitch, or what amounts to the same thing, the wave length of a beam of scattered X rays, using the apparatus shown in Plate 3, Figure 2. Rays from the target T of the X-ray tube were scattered by a block of carbon at R, and the wave length of the echoed rays was measured by an X-ray spectrometer. By swinging the X-ray tube in line with the slits, it was possible to get a direct comparison with the wave length of the original rays.

Plate 4, Figure 1, shows the result of the experiment. Above is plotted the spectrum of the original X-ray beam. Below is shown the spectrum of the X rays scattered in three different directions. A part of the scattered rays is of the original wave length; but, as you see, most of the rays are increased in wave length. This would correspond to a lower pitch for the echo than for the original sound.

As we have seen, this change in wave length is contrary to the predictions of the wave theory. If we take Einstein's idea of X-ray particles, however, we find a simple explanation of the effect. On this view, we may suppose that each photon of the scattered X rays is deflected by a single electron, Figure 5. Picture a golf ball bouncing from a football. A part of the golf ball's energy is spent in setting the football in motion. Thus the golf ball bounces off having less energy than when it struck. In the same way the electron from which the X-ray photon bounces will recoil, taking part of the photon's energy, and the deflected photon will have less energy than before it struck the electron. This reduction in energy of the X-ray photon corresponds, according to Planck's original quantum theory, to a

decrease in frequency of the scattered X rays, just as the experiments show. In fact, the theory is so definite that it is possible to calculate just how great a change in frequency should occur, and the calculation is found to correspond accurately with the experiments.

Trailing a photon.—If this explanation is the correct one it should, however, be possible to find the electrons which recoil from the impact of the X-ray particles. Before this theory of the origin of scattered X rays was suggested, no such recoiling electrons had ever been noticed. Within a few months after its proposal, however, C. T. R. Wilson succeeded in photographing the tracks left when electrons in

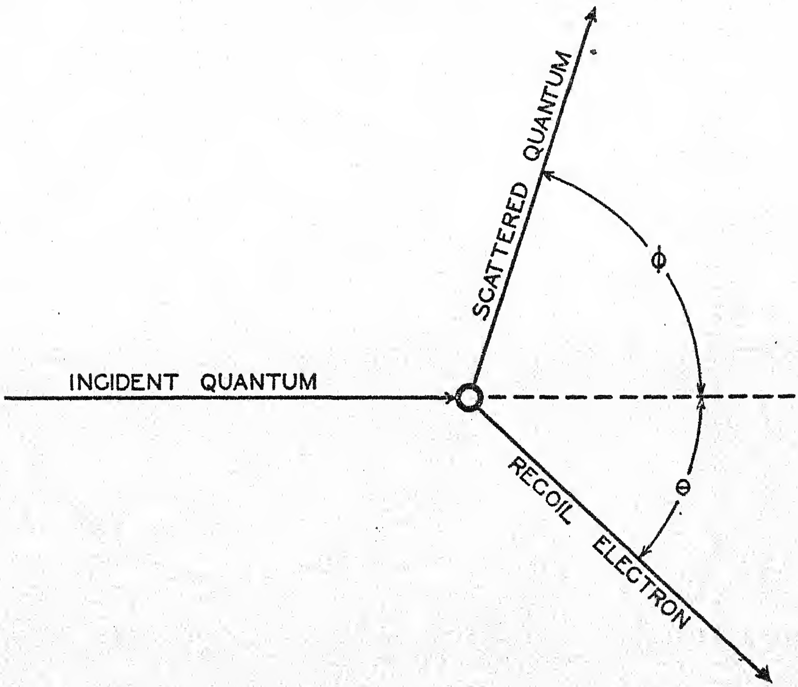


FIGURE 5.—Recoil of an electron. When an incident X-ray photon glances from an electron, the electron recoils from the impact, taking part of the photon's energy

air recoil from the X rays which they scatter. Plate 4, Figure 2, shows one of his typical photographs. The X rays here are going from left to right. At top and bottom will be seen the long trails left by two photoelectrons, which as we have seen take up the whole energy of a photon. In between are a number of shorter trails, all with their tails toward the X-ray tube. These are the electrons which have been struck by flying X-ray photons. Some have been struck squarely, and are knocked straight ahead. Others have received only a glancing blow, and have recoiled at an angle. Thus we have observed not only the loss in energy of the deflected photons,

as shown by the lowering in pitch of the X-ray echo, but we have found also the recoiling electrons from which the photons have bounced.

In order, however, to satisfy ourselves by a crucial test whether X rays act like particles, an experiment was devised which should enable us to follow the path of the photon after it has been deflected by an electron. In Figure 6 we see at the left what we may call the X-ray gun, which shoots a few X rays through a cloud-expansion chamber. In this chamber is photographed the trail of every electron set in motion by the X rays. So feeble a beam of X rays is used that on the average only one or two recoil electrons will appear at a time. Let us suppose, as in the figure, that the electron struck by the X-ray particle recoils downward. This must mean that the X-ray

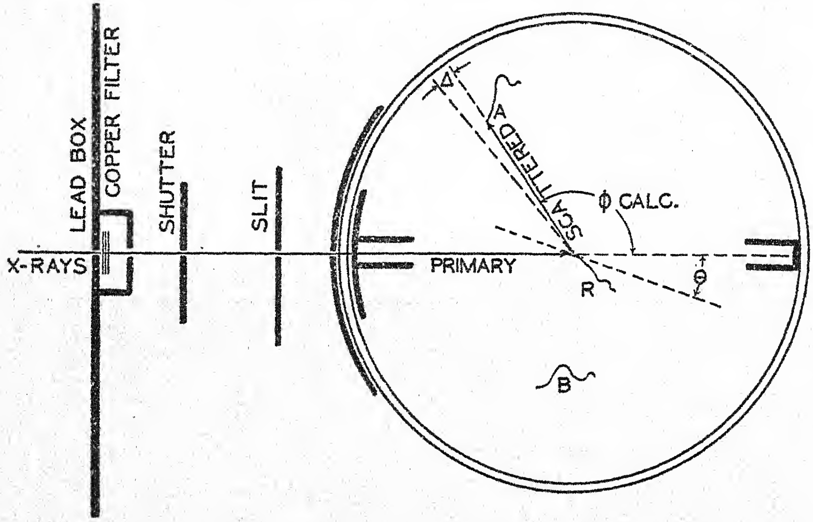


FIGURE 6.—Diagram of an experiment in which one observes both the recoiling electron and the direction in which the deflected photon proceeds

particle has been deflected upward toward A. If this X ray should strike another electron before it leaves the chamber, this event must occur at some point along the line OA. It can not occur on the same side as the recoil electron. If, however, the X ray is a wave, spreading in all directions, there is no more reason why the second electron associated with the scattered ray should appear at A than at B. A series of photographs which shows the relation between the direction of recoil of the scattering electron R and the location of the second electron struck by the scattered X ray, thus affords a crucial test between the conceptions of X rays as spreading waves and X rays as particles.

From a large number of photographs taken in this manner it has become evident that an X ray is scattered in a definite direction,

like a particle. But if X rays, so also all the rest of the family of electromagnetic radiations. It would thus seem that by these experiments Einstein's notion of light as made up of particles is established.

THE PARADOX OF WAVES AND PARTICLES

We thus seem to have satisfactory proof from our interference and diffraction experiments that light consists of waves. The photoelectric and scattering experiments afford equally satisfactory evidence that light consists of particles. How can these two apparently conflicting concepts be reconciled?

Electron waves.—Before attempting to answer this question let us notice that this dilemma applies not only to radiation but also in other fundamental fields of physics. When the evidence was growing strong that radiation, which we had always thought of as waves, had also the properties of particles, L. de Broglie asked, may it not then be possible that electrons, which we know as particles, may have the properties of waves? An extension of Planck and Einstein's quantum theory enabled him to calculate what the wave length corresponding to a moving electron should be. In photographs like Plate 3, Figure 1, and Plate 4, Figure 2, we have ocular evidence that electrons are very real particles indeed. Nevertheless, De Broglie's suggestion was promptly subjected to experimental test by Davisson and Germer at New York, and later by Thomson, Rupp, Kickuchi, and others.

Let us consider Thomson's experiments, which are typical of them all. Our crucial evidence for the wave character of light was the fact that light could be diffracted by a grating of lines ruled on glass. X rays were diffracted in the same way; but before this had been shown possible, it was found that X rays could be diffracted by the regularly arranged atoms in a crystal. The layers of atoms took the place of the lines ruled on glass. Plate 5, Figure 1, shows how this experiment has been done by Hull, at Schenectady. X rays pass through a pair of diaphragms and a mass of powdered crystals placed at C, and strike a photographic plate at P. Rays diffracted by the layers of atoms in the crystal strike at such points as P_1, P_2, etc., giving rise to a series of rings about the center. If a mass of powdered aluminum crystals is placed at C, Hull obtains the photograph shown in Plate 5, Figure 2. You see the central image, and around it the diffraction rings. It was this crystal diffraction that first gave convincing evidence that X rays, like light, consist of waves.

G. P. Thomson has performed a precisely similar experiment with electrons. The X-ray beam in the last slide was replaced by a beam of cathode electrons, and gold leaf took the place of the aluminum. The resulting photograph is shown in Plate 5, Figure 3. Though it

is not quite as sharp as the photograph taken with the X rays, we can see distinctly the central image, and several rings of diffracted electrons. If Plate 5, Figure 2, demonstrated the wave character of X rays, does not Plate 5, Figure 3, prove equally definitely the wave character of electrons?

We are thus faced with the fact that the fundamental things in nature, matter, and radiation, present to us a dual aspect. In certain ways they act like particles, in others like waves. The experiments tell us that we must seize both horns of the dilemma.

A SUGGESTED SOLUTION

During the last year or two there has gradually developed a solution of this puzzle, which though at first rather difficult to grasp, seems to be free from logical contradictions and essentially capable of describing the phenomena which our experiments reveal. A mere mention of some of the names connected with this development will suggest something of the complexities through which the theory has gradually gone. There are Duane, Slater, and Swann in this country, De Broglie in France, Heisenberg and Schrödinger in Germany, Bohr in Denmark, Dirac in England, among others, who have contributed to the growth of this explanation.

The point of departure of this theory is the mathematical proof that the dynamics of a particle may be expressed in terms of the propagation of a group of waves. That is, the particle may be replaced by a wave train—the two, so far as their motion is concerned, may be made mathematically equivalent. The motion of a particle such as an electron or a photon in a straight line is represented by a plane wave. The wave length is determined by the momentum of the particle, and the length of the train of waves by the precision with which the momentum is known. In the case of the photon, this wave may be taken as the ordinary electromagnetic wave. The wave corresponding to the moving electron is called by the name of its inventor, a De Broglie wave.

Consider, for example, the deflection of a photon by an electron on this basis, that is, the scattering of an X ray. The incident photon is represented by a train of plane electromagnetic waves. The recoiling electron is likewise represented by a train of plane De Broglie waves propagated in the direction of recoil. These electron waves form a kind of grating by which the incident electromagnetic waves are diffracted. The diffracted waves represent in turn the deflected photon. They are increased in wave length by the diffraction because the grating is receding, resulting in a Doppler effect.

In this solution of the problem we note that before we could determine the direction in which the X ray was to be deflected, it was necessary to know the direction of recoil of the electron. In this

respect the solution is indeterminate; but its indeterminateness corresponds to an indeterminateness in the experiment itself. There is no way of performing the experiment so as to make the electron recoil in a definite direction as a result of an encounter with a photon. It is a beauty of the theory that it is determinate only where the experiment itself is determinate, and leaves arbitrary those parameters which the experiment is incapable of defining.

It is not usually possible to describe the motion of either a beam of light or a beam of electrons without introducing both the concepts of particles and waves. There are certain localized regions in which at a certain moment energy exists, and this may be taken as a definition of what we mean by a particle. But in predicting where these localized positions are to be at a later instant, a consideration of the propagation of the corresponding waves is usually our most satisfactory mode of attack.

Attention should be called to the fact that the electromagnetic waves and the De Broglie waves are according to this theory waves of probability. Consider as an example the diffraction pattern of a beam of light or of electrons, reflected from a ruled grating, and falling on a photographic plate. In the intense portion of the diffraction pattern there is a high probability that a grain of the photographic plate will be affected. In corpuscular language, there is a high probability that a photon or electron, as the case may be, will strike this portion of the plate. Where the diffraction pattern is of zero intensity, the probability of a particle striking is zero, and the plate is unaffected. Thus there is a high probability that a photon will be present where the "intensity" of an electromagnetic wave is great, and a lesser probability where this "intensity" is smaller.

It is a corollary that the energy of the radiation lies in the photons, and not in the waves. For we mean by energy the ability to do work, and we find that when radiation does anything it acts in particles.

In this connection it may be noted that this wave-mechanics theory does not enable us to locate a photon or an electron definitely except at the instant at which it does something. When it activates a grain on a photographic plate, or ionizes an atom which may be observed in a cloud expansion chamber, we can say that the particle was at that point at the instant of the event. But in between such events the particle can not be definitely located. Some positions are more probable than others, in proportion as the corresponding wave is more intense in these positions. But there is no definite position that can be assigned to the particle in between its actions on other particles. Thus it becomes meaningless to attempt to assign any definite path to a particle. It is like assigning a definite path to a ray of light: The more sharply we try to define it by narrow slits, the more widely the ray is spread by diffraction.

If it were possible to photograph instantaneously the photons in an intense beam of light, we might expect them to have somewhat the appearance of Figure 7. Where the electric field of the corresponding electromagnetic wave is a maximum, there will be a maximum density of distribution of the photons. There is, however, this defect with our picture, that there seems to be no possible way in which we can experimentally locate the individual photons within the wave. Our picture must thus be considered to be a purely imaginary one. It will, however, serve to indicate that the conceptions of waves and particles are not irreconcilable.

Perhaps enough has been said to show that by grasping both horns it has been found possible to overcome the dilemma. Though no simple picture has been invented affording a mechanical model of a light ray, by combining the notions of waves and particles a

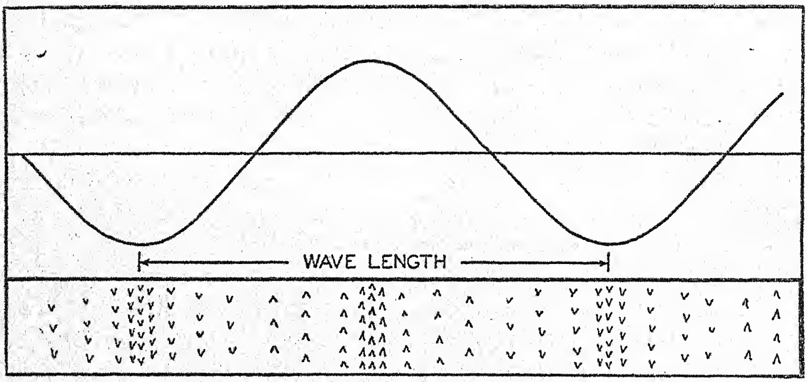
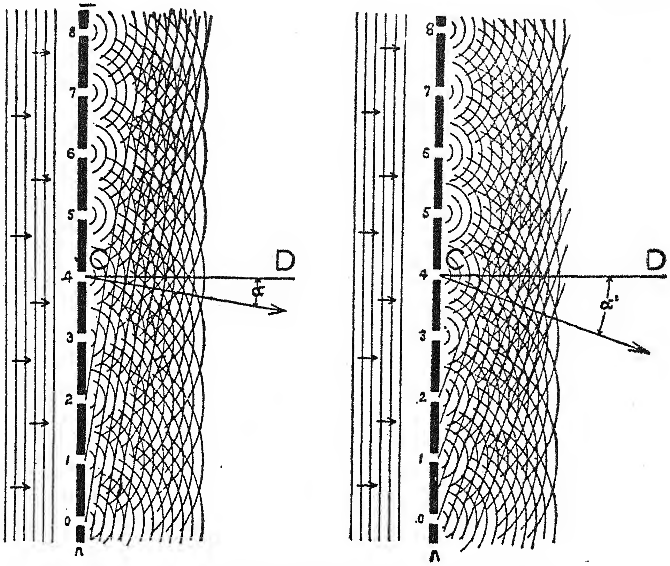


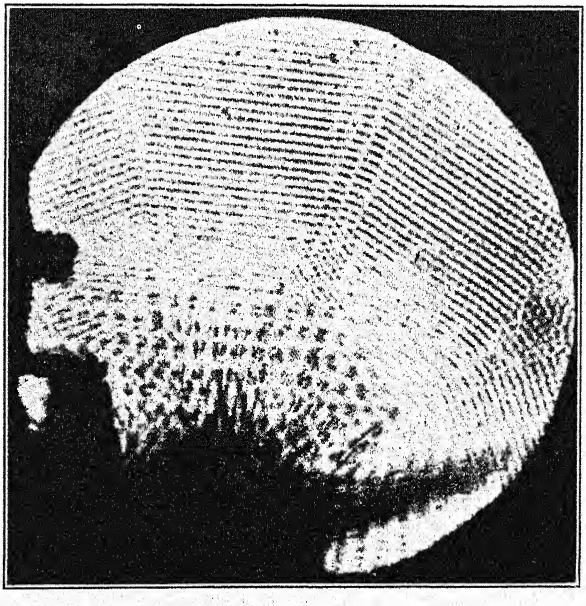
FIGURE 7.—Waves of photons. The curve represents a continuous electromagnetic wave; below the curve the wave is represented as successive sheets of photons

logically consistent theory has been devised which seems essentially capable of accounting for the properties of light as we know them.

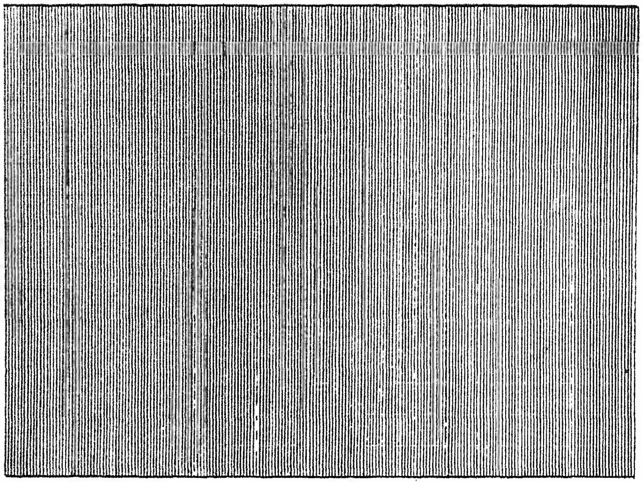
Radio rays, heat rays, visible and ultra-violet light, all are thus different varieties of light. We find from experiments on diffraction and interference that light consists of waves. The photoelectric effect and the scattering of X rays give equally convincing reasons for believing that light consists of particles. For centuries it has been supposed that the two conceptions are contradictory. Goaded on, however, by obstinate experiments, we seem to have found a way out. We continue to think of light propagated as electromagnetic waves; but whenever the light does something, it does it as photons. Light is thus in some respects similar to waves and in others to particles, but can not be identified completely with either.



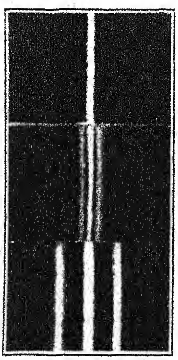
1. DIAGRAM OF THE DIFFRACTION OF WAVES BY A GRID



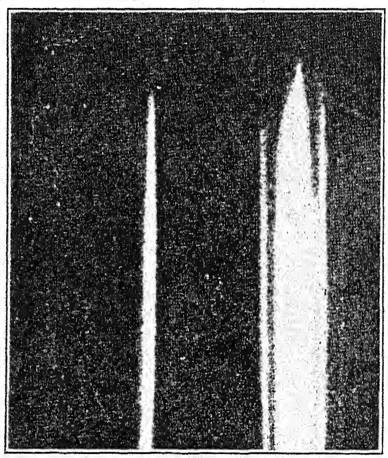
2. PHOTOGRAPH OF MERCURY RIPPLES DIFFRACTED BY A GRID



1. A PATTERN OF 200 REGULARLY SPACED LINES WHICH WHEN PHOTOGRAPHED ONTO A LANTERN SLIDE FORMS A DIFFRACTION GRATING FOR EXPERIMENTS ON LIGHT



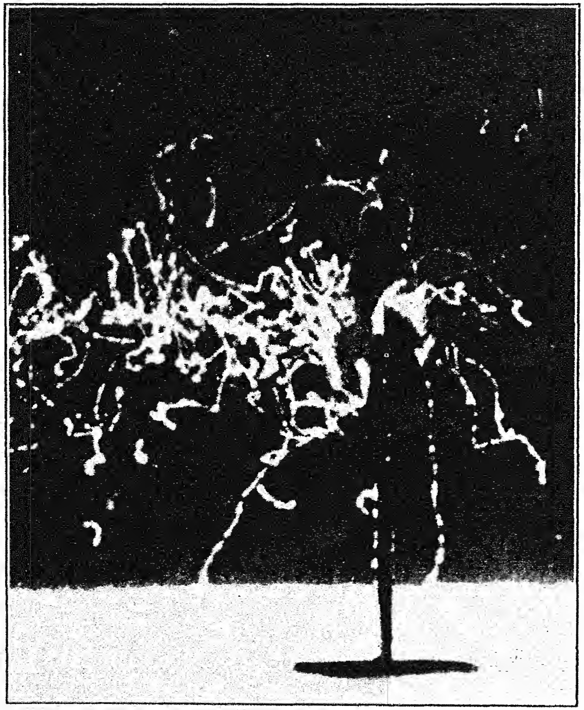
2



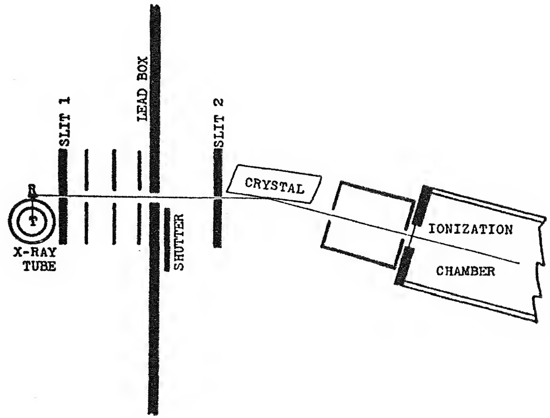
3

2, 3. DIFFRACTION OF LIGHT AND X RAYS

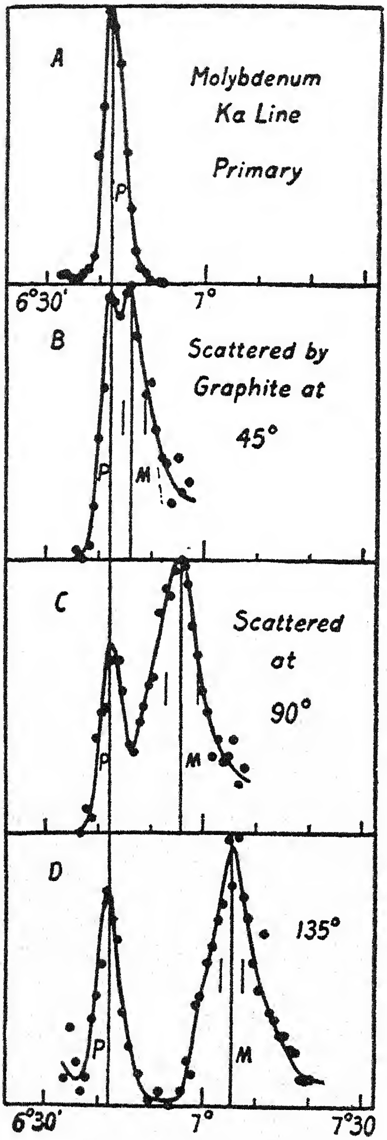
2, The upper portion is the direct beam, the middle portion that through 100 lines to the inch, and the lower portion photographed through a grid of 330 lines to the inch. 3, Diffraction pattern of X rays. *D* is the direct beam, *O* the directly reflected beam, and the other lines are due to diffraction.



1. PHOTOGRAPH OF THE TRACKS OF PHOTOELECTRONS EJECTED FROM COPPER BY X RAYS. (WILSON)

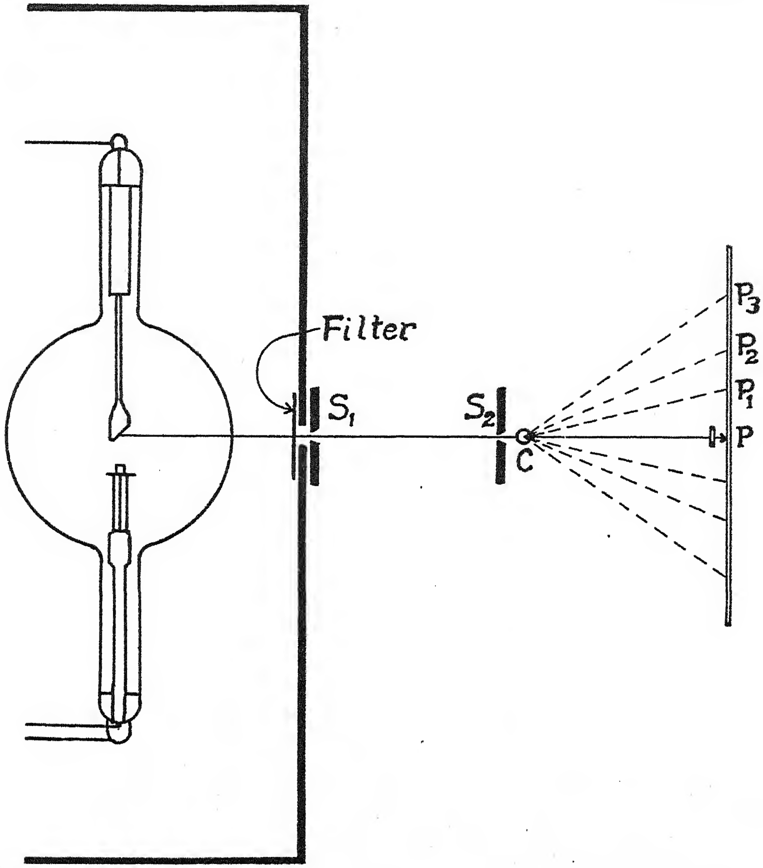


2. THE WAVE LENGTH OF THE X RAYS SCATTERED FROM A PIECE OF CARBON AT R IS MEASURED BY REFLECTION FROM A CRYSTAL

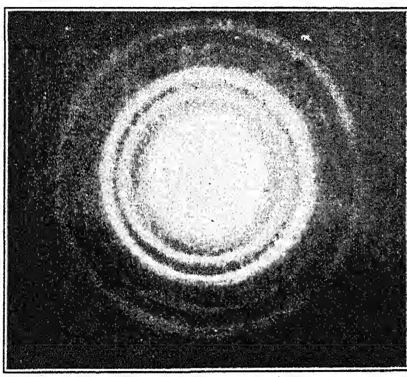


1. SPECTRA OF SCATTERED X RAYS (BELOW) COMPARED WITH THE SPECTRUM OF THE ORIGINAL X RAY

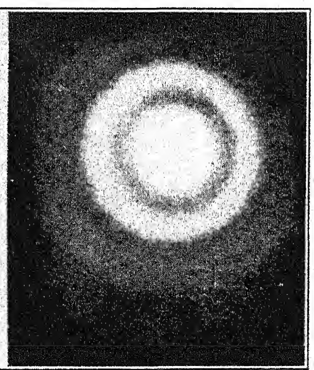
2. RECOIL ELECTRONS. THE X RAYS ARE GOING FROM LEFT TO RIGHT AND THE SHORTER TRACKS PROCEED ALMOST IN THE DIRECTION OF THE X RAYS



1. HULL'S ARRANGEMENT FOR DIFFRACTING A BEAM OF X RAYS BY A MASS OF POWDERED CRYSTALS



2



3

2. THE DIFFRACTION PATTERN PRODUCED WHEN A BEAM OF X RAYS TRAVERSES A MASS OF ALUMINUM CRYSTALS. (HULL)

3. THE DIFFRACTION PATTERN PRODUCED WHEN A BEAM OF ELECTRONS TRAVERSES A MASS OF GOLD CRYSTALS. (G. P. THOMSON)

ARTIFICIAL COLD [1]

By Gordon B. Wilkes

[With 3 plates]

The appearance of refrigerating machinery for domestic use has created among laymen an abiding interest in the mechanical methods of artificial cooling. Domestic refrigeration of one kind or another is here to stay and it is probable that an extensive development of cooling and ventilating machinery for the home is just around the corner. Already many of our theaters and public halls have installed devices for cooling the air during the warm months, and only a short time ago a combined heating and air cooling unit was advertised for private residences. If the temperature of our living quarters drops 8° or 10° to around 60° F., we feel uncomfortable and start the heating system; but if a warm day arrives in summer with a temperature 20° or 30° above 70° F., we are uncomfortable because we have had no easy means of cooling the air. I can see no reason why, during the next few years, it will not become a rather common practice in the more expensive homes to have some means of cooling the air in summer as well as a means of heating it to a comfortable temperature during winter.

Some fifty-odd years ago, Lord Kelvin (Sir William Thomson) demonstrated, by means of a simple lecture-table experiment, that the sensation of cold was a purely relative matter. He placed three basins of water on the table: one hot, one ice cold, and the third at room temperature. Placing his right hand in the hot water and his left in the cold water for a few moments, he quickly transferred both hands to the basin with water at room temperature. In attempting to describe the sensation he was forced to conclude that either his left hand or his right hand was deceiving him, for the water felt cold to his right and warm to his left hand. Since, therefore, the sensation of cold is largely a relative matter, we shall assume for our purposes that cold signifies any temperature below 70° F., ordinary room temperature. Let us also agree to understand that all of the temperatures referred to are in degrees on the Fahrenheit scale, the one we use for most work outside the laboratory.

[1] Reprinted by permission from The Technology Review, March, 1929.

Primitive man found that an over supply of meat from a successful hunt could be preserved for a longer period of time if he kept it in an underground cavern, a well, or in the water from a spring or other relatively cool place. In a temperate climate like that in New England, the temperature of the air may vary as much as 40° in a day and as much as 100° throughout the year. The daily variation affects underground temperatures only to a slight extent at a depth of 2 or 3 feet, while the annual variation is lost at a depth of 25 to 50 feet. There the temperature remains practically constant throughout the year and usually approximates the average yearly temperature of the surface. For this reason, water from deep wells usually has a temperature that is the same throughout the year; similarly, spring water is at almost constant temperature because this water comes from a considerable depth below the ground surface. Anyone who has had the opportunity to visit caves in different seasons, nearly always finds them warm in winter and cool in summer. This and the common method of placing water pipes a few feet underground to prevent freezing in cold weather, illustrate the fact that the variation in air temperature soon disappears at a sufficient depth underground.

Nearly everyone is familiar with the use of ice and salt to produce temperatures low enough to freeze ice cream. If ice and salt are mixed in proper proportions, it is not difficult to produce a temperature of 0° F., and by using calcium chloride in place of salt, considerably lower temperatures may be attained. There are many other substances that may be used with ice to produce temperatures below the freezing point of water, such as ammonium nitrate, alcohol, hydrochloric acid, and so on. The use of niter (potassium nitrate) with snow or ice has long been known. As early as 1550 it is said the Roman nobles cooled their wines by snow and niter.

In temperate climates, ice has for many years been used to produce low temperatures. Its melting point is 32° F. which represents the lowest temperature that one can expect to reach with the use of ice alone, but the ordinary domestic ice box is more frequently in the neighborhood of 50° F. as a recent survey of a large number of refrigerators determined. Despite the enormous sales of electrical and gas-heated refrigerators in recent years, ice will continue to be used, probably in somewhat lesser quantities, for many years to come, because of the low cost and the lack of many minor troubles that are bound to arise from any mechanical unit.

The cooling effect of evaporation has been utilized for centuries by the peoples living in hot, dry climates who store their drinking water in porous earthenware jars. Moisture oozes through the walls to the outside of the vessel where it evaporates, the effect of which is sufficient to lower the temperature of the water from 10° to 20°

below that of the surrounding air. This simple primitive expedient, strangely enough, contains the germ of the principle upon which are based all of the mechanical refrigeration systems now in domestic use. The principle is this: that evaporation—or what is the same thing, the transition from the liquid to the vapor state—requires a large amount of heat energy, which must be supplied by the liquid itself or the immediate surroundings. If one is boiling water, most of the heat energy comes from the heated air around the vessel and the air is thereby cooled. If water is evaporating from the surface of an earthenware water jar, the heat comes from the vessel and the surrounding air, both of which are cooled in the process.

One must also recognize the fact that the temperature at which a liquid boils (its "boiling point") depends upon the pressure. With the atmospheric pressure as it is at sea level, water boils at approximately 212° F., but if the pressure be increased twenty times, the boiling point is increased to about 417° F. If the pressure be sufficiently lowered, one can make water boil at room temperature or even at 32°, the ordinary freezing point.

This we can readily demonstrate on the lecture table by repeating what is known as Leslie's Experiment. If we place some water at room temperature in a thermos bottle and reduce the pressure until the water boils, heat will be drawn from the remaining water (since little can come from the surroundings) and it will become cooler. Then if we continue to reduce the pressure in order to keep the water boiling, it will soon reach a temperature of 32° F. and some of the water will be converted into ice, inasmuch as water does not normally exist in the liquid state at a temperature below 32° F.

The boiling points of all other liquids vary with the pressure and consequently all that has been said in regard to water applies equally well to ammonia, sulphur dioxide, carbon dioxide, and so on; only, of course, the temperature-pressure conditions may be very different from those of water. This principle of cooling by evaporation or boiling of various liquids is, as I have already mentioned, the foundation upon which nearly all of our refrigerating machines are constructed.

Refrigerating units for home use are, in general, of two different types—those using a small electrically driven pump, the compression type, and those using heat generated by a gas or kerosene oil burner, the absorption type. The operating principle of each is simple, the former particularly so. A suitable liquid (called the refrigerant) such as ammonia, sulphur dioxide, carbon dioxide, methyl chloride, or ethyl chloride, is placed in the cooling coil inside the refrigerator cabinet, where it is made to "boil" by having the pressure upon it reduced with the motor-driven pump. This pump receives the vapor from the coil at low pressure, compresses it, and passes it along to

either an air-cooled or a water-cooled condenser. The compressing of the vapor increases its temperature so that when it reaches the condenser the high pressure and the cooling action of the condenser are enough to liquefy it. The liquid refrigerant is then directed back into the cooling coil in the refrigerator, and the cycle is repeated.

Electrical refrigeration is very similar to a steam heating plant in a private residence. There water is boiled over the fire box and the steam or water vapor carried by pipes to radiators where on condensing it gives up heat to the room. The condensed steam then returns to the boiler where the cycle is repeated. In other words, the boiling of the water keeps the boiler relatively cool and thus acts as a refrigerating system for the boiler that would otherwise become very hot. Heat is transferred from the boiler to the radiators in steam heating, while in electrical refrigeration, heat is transferred from the refrigerator to the condenser coils in much the same way. In steam heating, the water is made to boil by the addition of heat, while in electrical refrigeration the liquid is made to boil by the reduction in pressure caused by the pump.

The Audiffren unit, the first entirely self-contained machine, is interesting. It was invented by a French priest, Abbé Audiffren, some 25 years ago, and placed on a commercial basis in this country in 1911. The unit resembles a large dumb-bell, with one ball, containing the compressor, revolving in cooling water and with the other ball used as an expansion or cooling chamber. This latter ball can be immersed in brine or water for cooling purposes. The unit is charged with a mixture of sulphur dioxide and lubricating oil at the factory, which is sufficient for many years' use. The photograph (pl. 2, fig. 1) shows one of the original French machines that was sent to the Heat Measurements Laboratory of the Massachusetts Institute of Technology in the summer of 1911. This particular machine has been in intermittent service for the past 18 years, operating perfectly, and it has never been opened for inspection or repairs.

"Refrigeration by heat" makes an interesting slogan, but the layman rarely understands the principles back of the absorption method of refrigeration, although more than 50 years ago small domestic refrigeration units using this principle were sold to the public. Cold water absorbs enormous quantities of ammonia gas, but if a solution of ammonia and water be heated much of the ammonia can be driven out of solution. Ferdinand Carré, many years ago, used two containers connected by a pipe, in one of which a strong solution of ammonia and water was placed. Adding heat to this solution by means of a charcoal fire, the ammonia was driven out and as the other container was kept cool by immersing it in water, the ammonia gas would condense there in increasing quantities until most of the ammonia was evolved. Now, if the weak solution were

cooled, the ammonia would be reabsorbed, thus reducing the pressure on the other chamber so that the ammonia liquid boiled, producing a considerable cooling effect. This type of machine is still being sold and if one is willing to heat the unit for about an hour each day with kerosene or gas, it will keep a refrigerator at a useful temperature for the preservation of food.

This same principle has been developed by many manufacturers so that there are large commercial machines using this process as a means of continuous refrigeration. There are also several domestic refrigerators using this principle with gas as the form of fuel for heating; one of these machines, in fact, operates without a single moving part, except for the thermostat control of the gas valve.

Another important principle of cooling is the Joule-Thompson Effect or the cooling of a gas by expansion from a high to a low pressure. If the gas can be made to do work while expanding, a still greater cooling effect will be produced and the economy of operation will be increased, since the gas in expanding can be made to help compress the incoming gas. There are some refrigerating machines based upon this principle, using air as the refrigerant.

Carbon dioxide is a by-product of many industries and consequently is an inexpensive gas. It is usually sold in the liquid form under a pressure of about 850 pounds per square inch. Nearly all substances can exist in three different states, solid, liquid, or gaseous, provided the temperature and pressure conditions are suitable. If sufficient heat is added to solid iron, it can be converted into the liquid state, and if the temperature could be raised still higher a point would be reached where it would be converted into iron vapor. We are all familiar with the three states of water, such as steam, water, and ice; and within the past 50 years we have learned that the so-called permanent gases can be converted to liquids or even solids, provided the temperature is sufficiently low and the pressure is suitable. Now, if a cylinder of liquid carbon dioxide under 850 pounds per square inch pressure is inverted so that when the valve is opened only liquid will escape, you will find that there is a great cooling effect, due to the vaporization of the liquid, since carbon dioxide can not exist as a liquid at room temperature and under atmospheric pressure. This cooling effect is so great that some of the escaping liquid is cooled to such a temperature that it can no longer exist as a liquid, but is converted to the solid state or carbon dioxide snow. If a strong cloth bag is tied over the outlet from the tank, the gas will pass through the bag but the solid or snow can be collected. This snow is at a temperature of 109° F. below zero and for many years has been used as a cooling agent in laboratory work. The snow itself sublimes or goes directly from the solid to the gaseous state under atmospheric pressure and does not make very good ther-

mal contact with materials that one wishes to cool; consequently, it is frequently mixed with alcohol or ether to overcome this disadvantage of poor contact.

Within the last few years methods have been devised to use this carbon dioxide snow industrially. The snow as formed above can be compressed in hydraulic presses so as to form a dense, hard cake with a specific gravity of about 1.1 or slightly heavier than water. This dense snow or "dry ice," as it is called, because it goes directly into a gas from the solid, is being used to a considerable extent for packing ice cream or frozen fish where the temperature must be kept considerably below the freezing point. One large manufacturer of ice cream in Cambridge, Mass., is shipping 75 per cent of his ice cream packed in carbon dioxide snow rather than with the old salt and ice mixture. One gallon of ice cream is placed in a corrugated cardboard box and then a small paper bag is placed on top containing from one to two pounds of "dry ice," depending upon the atmospheric temperature. This will keep the ice cream in excellent condition for from six to eight hours, and there are many obvious advantages, such as less bulk to the containers, inexpensive containers that can be discarded, thus saving a collection trip, and no wet mixture of salt and ice required.

Ice cream can be shipped long distances by this method and frozen fish have remained in freight cars for over five days without attention when packed with this material. It has been recently stated that in shipping ice cream from Philadelphia to New York City, 200 pounds of "dry ice" at from 5 to 10 cents per pound has replaced 3,000 pounds of water ice and 600 pounds of salt. In this case 3,400 pounds of extra freight is avoided besides the other advantages. Dry ice lasts exceptionally well even when exposed to a temperature of 70° F. Recently a 25-pound cake was left on the lecture table for 24 hours exposed to room temperature and even after that period of time 2 or 3 pounds were still left. When packed in insulated containers, it will, of course, last longer. It is reported that a New York apartment house is using it in all its refrigerators.

Another recent use of carbon dioxide snow is the carbon dioxide snow fire extinguisher. This is merely a tank of liquid carbon dioxide under pressure with a hose and nozzle connected so that when the valve is opened, carbon dioxide gas and snow will be delivered from the nozzle. This extinguisher is particularly effective on electrical fires, such as generators or telephone switchboards, because it will not conduct electricity and does not injure the electrical apparatus. It is also very effective on gasoline or oil fires. Since the gas is much heavier than air, the fire is smothered and the extremely low temperature of the snow cools the burning material below the ignition temperature.

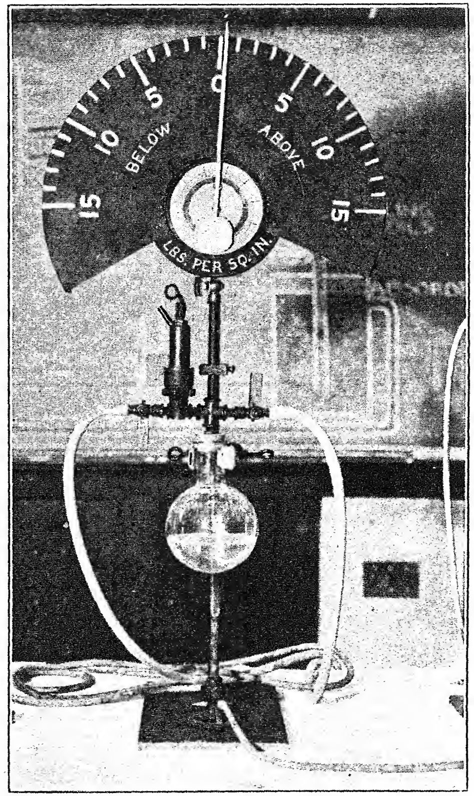
If air is compressed to some 3,000 pounds per square inch and then allowed to expand to atmospheric pressure, it is cooled approximately 50° F. With the aid of a regenerative coil, this cooled, expanded air can be forced into close contact with the high-pressure air, thus cooling the high-pressure air. If this process is continued, a point will soon be reached where the cooling effect will cause some of the escaping air to be cooled to the liquefaction temperature and liquid air can be collected at the bottom of the expansion coil. For some time after the discovery of the method of producing liquid air, the material was largely for laboratory use only, but now the commercial use has increased to such an extent that there is scarcely a large-sized city that does not have at least one liquid-air plant in operation. In the modern plants, the expanding air operates a compressor, thus increasing the efficiency over the earlier laboratory methods.

Air contains roughly 20 per cent oxygen and 80 per cent nitrogen, but the boiling point of nitrogen is 320° F. below zero while oxygen boils at only 297° F. below zero. Due to this difference in boiling temperatures the nitrogen tends to vaporize first and it is possible to separate these two substances by fractional distillation in much the same way as gasoline is separated from crude oil, but no external heat is required to boil liquid air because the normal boiling point is about 310° F. below zero.

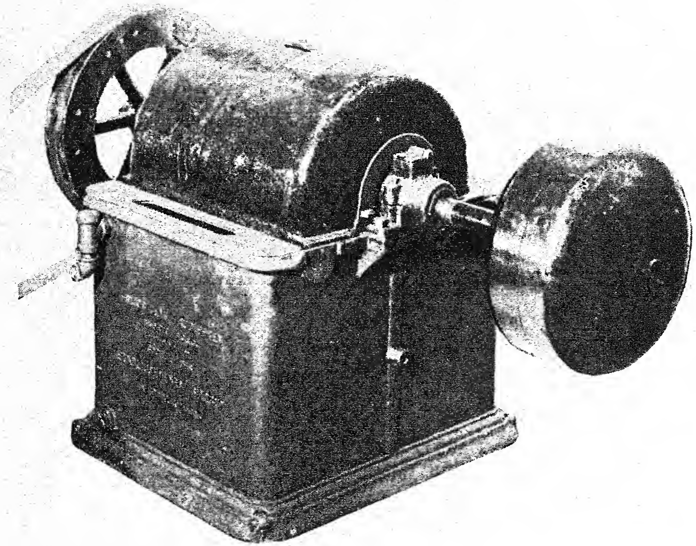
Liquid air is also used in high-vacuum work and is used for the production of helium from natural gas in Texas. A prominent mining engineer states that 90 per cent of the explosive work in the mines in Mexico is carried out with liquid oxygen as the explosive rather than gun powder. If blotting paper is rolled up and saturated with liquid oxygen and then tamped into a drilled hole, it can be ignited electrically and an explosion similar to that of gunpowder will result.

1. A PRIMITIVE WATER COOLER

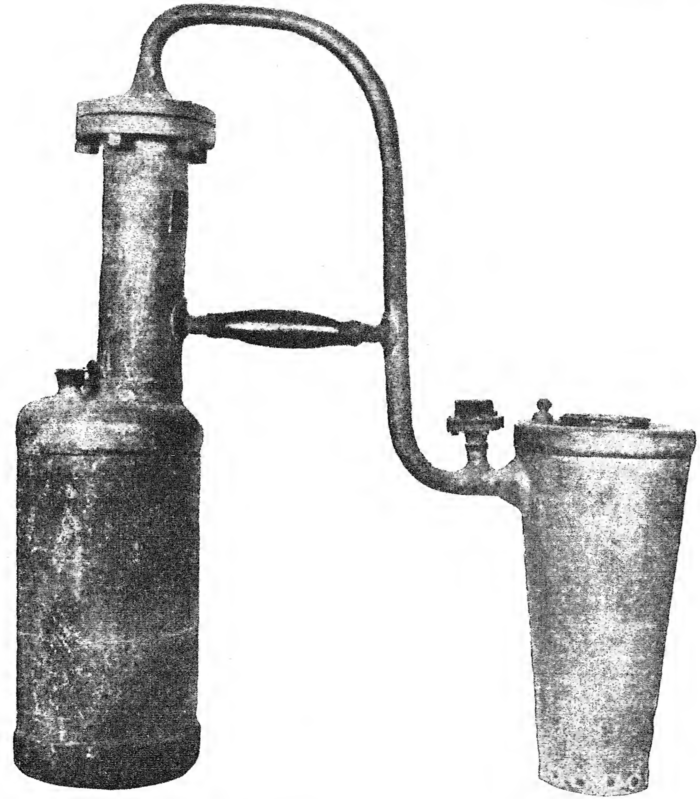
For centuries peoples in hot dry climates used porous earthenware jugs for cooling water. This one was made in Spain.



2. LECTURE-TABLE APPARATUS FOR SHOWING THE EFFECT OF PRESSURE ON THE BOILING POINT OF WATER

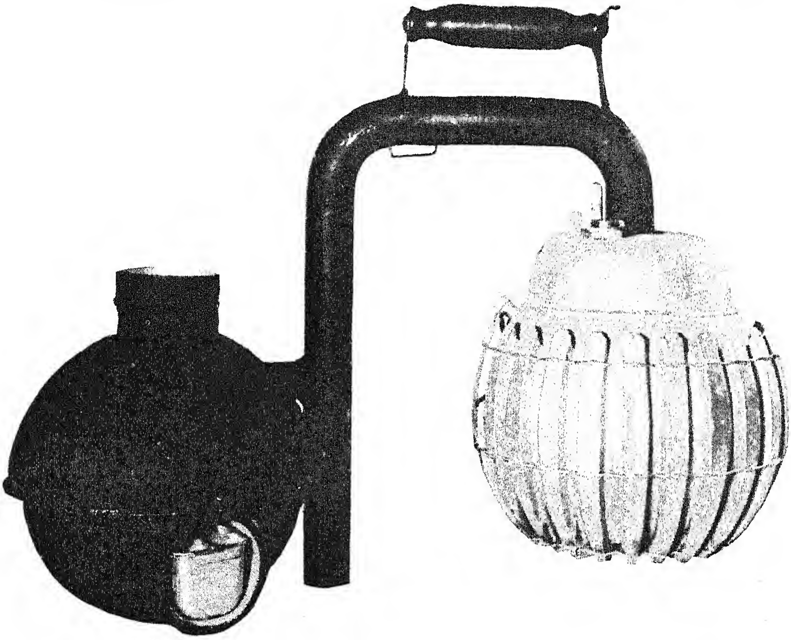


1. THE COMPLETELY SEALED AUDIFFREN REFRIGERATING UNIT DESCRIBED ON THE OPPOSITE PAGE

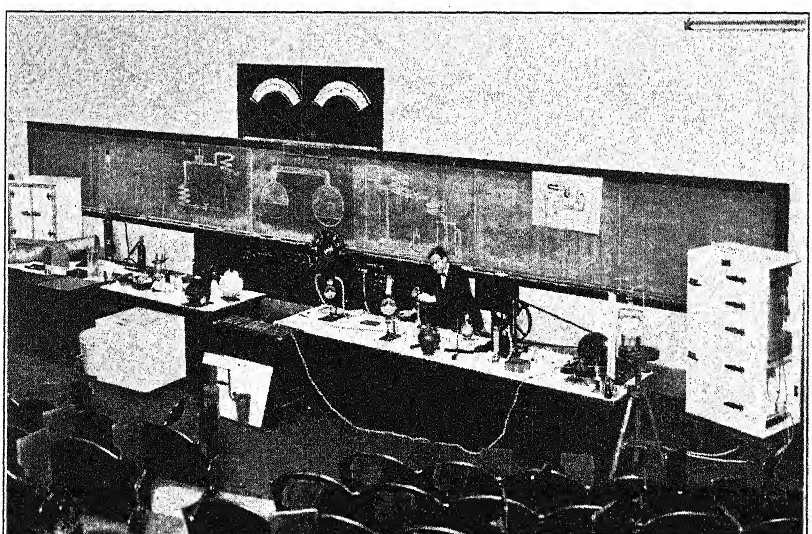


2. THE CARRÉ TYPE OF ABSORPTION REFRIGERATION UNIT USED 50 YEARS AGO

Heat is applied to the vessel at the left; the other is placed within the refrigerator cabinet.



1. A MODERN KEROSENE HEATED ABSORPTION PROCESS UNIT. THE BLACK BALL IS PLACED WITHIN THE CABINET



2. PROFESSOR WILKES WITH THE ELABORATE LECTURE-TABLE DEMONSTRATION HE ARRANGED FOR A POPULAR SCIENCE LECTURE

PHOTOSYNTHESIS [1]

By E. C. C. Baly, C. B. E., F. R. S.

Professor of Inorganic Chemistry, University of Liverpool

There is no process within the confines of chemistry which is of greater interest and importance than that by means of which the living plant prepares the food on which its life and growth depend. This food consists of starch and sugars, together grouped under the general name of carbohydrates, and of certain nitrogen-containing compounds known as proteins. The material from which the plant starts is carbonic acid, or a solution of carbon dioxide, which it obtains from the air, in water which it obtains through its roots from the soil. From this substance alone the plant is able to prepare its supply of carbohydrates, and it is true to say that this chemical process is the fundamental basis of the whole of terrestrial life. This may truly be asserted because the production of the proteins is very closely associated with it and the initial stage is common to the two.

The formation of carbohydrates from carbonic acid when expressed by a chemical equation looks simple enough. There is no doubt that the first product of the process that can be recognized in the plant is a simple sugar, and thus the equation can be written

$$6H_2CO_3 = C_6H_{12}O_6 + 6O_2$$

where the simple carbohydrate is either glucose or fructose. These simple sugars undergo condensation immediately they are formed to give cane sugar or one of the starches, and these changes can readily be written as simple chemical equations.

The mechanism by means of which the plant achieves the synthesis of these complex compounds from carbonic acid has long been a mystery to chemists and to botanists. It is known that the agency used by the plant to effect its purpose is sunlight, and thus the term photosynthesis has been applied to the operation. It is also known that the plant makes use of certain pigments, such as chlorophyll,

[1] Presented at the weekly evening meeting of the Royal Institution of Great Britain, Feb. 3, 1928. Reprinted by permission of the Royal Institution.

and it is to these that the color of the leaves is due. The mystery of it all lay in the fact that no one knew what actually takes place, and, indeed, the more chemists and botanists explored, the more puzzling did the problem seem to be.

Perhaps the most puzzling fact of all is that the plant only makes use of sunlight, when all our previous knowledge of light reactions leads us to believe that such light is quite incapable of inducing photosynthesis. This may readily be understood if the amount of energy involved in the synthesis is considered. It has been proved experimentally that in order to synthesize 1 gram molecule (180 grams) of glucose or fructose there must be supplied to the carbonic acid a minimum quantity of energy equal to 673,800 calories. While it is known that the plant manages in some way to absorb the necessary energy in the form of light, the physicist tells us that it can not directly absorb enough energy from sunlight. Thus the photosynthesis can be brought about by red light of the wave length $660\mu\mu$ when the energy directly absorbed can only be 260,000 calories which is far below the minimum quantity required.

The experience gained from the ordinary reactions of photochemistry leads to the belief that if it is required to convert carbonic acid into sugars by means of light alone, it will be necessary to use ultra-violet light which is absorbed by carbonic acid, that is to say, light of wave length $210\mu\mu$. It is obvious from this that some unknown factor is operating in vital photosynthesis.

In any endeavor to elucidate the mystery, it is evident that the first line of inquiry must be to study the action of the short wave ultra-violet light upon carbonic acid. This was first investigated by Moore and Webster in 1913, who found no evidence of any reaction taking place. They found, however, that in the presence of certain catalysts, such as colloidal iron hydroxide, small quantities of formaldehyde were produced. Since these results appeared to be at variance with general experience in photochemical investigations, they were again examined some years later in Liverpool, and it was then found that when a stream of carbon dioxide was passed through water irradiated by the light from a quartz mercury lamp, small quantities of formaldehyde were produced. This result seemed to be very satisfactory, since the formaldehyde could be looked upon as an intermediate stage on the way to carbohydrates, especially in view of the fact that Moore and Webster had proved that formaldehyde was converted by light into substance, with properties similar to the simple sugars.

Our observations were criticized by Porter and Ramsperger, who stated that if rigid precautions were taken to guard against the presence of every trace of impurity, no formaldehyde was produced. The suggestion was implied by them that the origin of the formaldehyde

was to be found in some unknown impurity. There is, however, an alternative possibility, and one which is more in keeping with the known facts of the natural photosynthesis in the living leaf. There is no doubt that in this reaction the carbonic acid is converted directly into carbohydrates and that formaldehyde as such is not produced, and it seemed that the most probable explanation of the discrepancy between our results and those of Porter and Ramsperger was that the action of the ultra-violet light is to establish a photochemical equilibrium.

$$6H_2CO_3 \rightleftarrows C_6H_{12}O_6 + 6O_2,$$

which reverts to carbonic acid again in the dark. In the presence of oxidizable impurities a small amount of carbohydrates will be formed, which will be photochemically decomposed to formaldehyde. This decomposition of all the carbohydrates by means of ultra-violet light is well known.

There is no need to give here the details of the experiments which were carried out to test this view, and it is sufficient to say that conclusive proof was obtained of the reality of the equilibrium; that is to say, carbohydrates were found to be present in the solution during irradiation by ultra-violet light, and these vanished very quickly after the irradiation was stopped.

This gave us at once a starting point, because it seems evident that if a harmless inorganic reducing agent were added to the solution, carbohydrates should be formed in quantity on exposure to the ultra-violet light. Such a reducing agent is ferrous bicarbonate, and great hopes were raised when it was found that a saturated solution of this compound, which was completely colorless when prepared, gave a copious precipitate of ferric oxide on exposure to ultra-violet light. It was evident that the oxidation took place by reason of the oxygen in the carbohydrate equilibrium in accordance with the equation

$$4Fe(HCO_3)_2 + O_2 = 2Fe_2O_3 + 4H_2O + 8CO_2$$

and indeed it was found that on evaporation of the exposed solution a simple sugar was obtained. The quantity produced was very disappointing and far less than was anticipated, and the conclusion was forced upon us that some unknown factor was taking part in the process.

During many unsuccessful endeavors to improve the yield of the carbohydrates, it was noticed that the ferric oxide was not produced in the body of the solution, but only on the walls of the quartz containing vessels and on the surface of the iron rods used to make the bicarbonate. This led us to suspect that the surface was a determining factor, and we at once changed the experimental method so as to

increase the surface as much as possible. In order to secure this a suspension of pure aluminium powder in water maintained by a stream of carbon dioxide, was exposed to ultra-violet light. Increased yields of carbohydrates were at once obtained, but it was also found that the best yields were obtained when the aluminium powder had been allowed to coat itself with hydroxide by remaining in contact with the water before the exposure to light. This latter observation very materially changed our ideas, since it established the fact that the surface phenomenon is of far greater importance than the reducing action, and indeed raised the question as to whether the latter plays any rôle at all in the process.

In order finally to decide this question an aqueous suspension of pure and freshly prepared aluminium hydroxide, maintained by a stream of carbon dioxide, was exposed to ultra-violet light. There was obtained after filtration and evaporation of the solution a quantity of carbohydrates equal in weight to that produced when aluminium powder was used. This conclusively proved the fundamental significance of the rôle played by the surface, and at the same time the reducing action was found to be entirely unnecessary. Identical results were obtained with other powders, such as aluminium, zinc, and magnesium carbonates.

During the course of these experiments it occurred to one of my students (Dr. W. E. Stephen) that if a green powder were used in place of the white ones the photosynthesis might take place in visible light, the green color being suggested by the green color of the plant-pigment chlorophyll. This was found actually to be the case, since a suspension of nickel carbonate maintained by a stream of carbon dioxide in water, on exposure to the light from an ordinary tungsten filament lamp, gave a larger yield of carbohydrates than any of the white powders in ultra-violet light. We soon found that there was no especial virtue in the green color, and that equally good results were given by pink cobalt carbonate.

Apart from the interest which accrues from the fact that the photosynthesis is thus achieved in a way which shows a real analogy with the natural phenomenon, the method with a colored surface and visible light has the very material advantage in that the danger of photochemical decomposition by ultra-violet light is completely eliminated, with the result that the products are obtained in a purer state.

From the above description of the direct photosynthesis of carbohydrates from carbonic acid in the laboratory several points arise which require discussion and explanation. In the first place it may be stated that the most rigid control experiments which we could devise have definitely established the fact that the carbohydrates are not due to the presence of impurities.

One of the greatest difficulties met with in this work was the preparation of the various materials used for the surfaces, since it is absolutely essential that these be completely free from any trace of alkali. It is well known that when metallic hydroxides and carbonates are precipitated they tend to absorb the alkali, and the removal of this is extraordinarily troublesome. The absence of any alkaline reaction in the filtrate after the powder has been boiled with water is no criterion of purity, and the only satisfactory method is to pass carbon dioxide into a suspension of the powder in water for two hours in the dark, and the filtrate after concentration must yield no weighable quantity of alkaline carbonate.

It was frequently found that the carbonates of nickel and cobalt, even when completely freed from alkali, were entirely ineffective in promoting photosynthesis. These can, however, be activated either by heating to 120° or by exposure in thin layers to ultra-violet light, and this fact afforded a very convincing method of carrying out controls. A quantity of one of these inactive powders gives no trace of carbohydrates when exposed to visible light in the manner described. The same sample of powder when activated and used in the same apparatus, with the same water, the same light, and carbon dioxide from the same source, gives a good yield of carbohydrates. So, once and for all, is all doubt removed as to the possible effect of impurities.

For the benefit of those who may wish to repeat these experiments, it may be stated that more recently it has been found possible to prepare nickel carbonate by a new method which is free from the objections characteristic of its precipitation by means of alkali carbonate. A solution of carbonic acid in conductivity water is electrolyzed, the electrodes being made of nickel plates. The current is taken from a 220-volt circuit, and sufficient resistance is intercalated to reduce the current density to from 1 or 2 amperes per square decimeter. The electrolyte is cooled by glass coils through which a stream of water is maintained. With electrodes 190 square centimeters in area it is possible to prepare 30 grams of pure carbonate in 24 hours. The carbonate should be collected every day by filtration, and it is advisable to clean the electrodes with emery paper every third day.

To sum up the results, so far as they have been described, it has been found possible in the laboratory to produce carbohydrates directly from carbonic acid by a process which is physically similar to that of the living plant. The essential difficulty in our understanding of the natural photosynthesis has been solved, namely the use of visible light as the agent in a process which the elementary laws of photochemistry taught us to believe could only be achieved

by means of ultra-violet light. As so often happens the explanation when found is very simple. The great amount of energy required to convert the carbonic acid into carbohydrates is supplied to it in two portions, one by the surface and the other by the visible light.

Nothing has as yet been said of the actual carbohydrates which have been photosynthesized in the laboratory. Although as yet our information is still meager, there is no doubt that the photosynthetic sirup is a mixture containing glucose or fructose, or both. There are also present more complex carbohydrates, which can be resolved to the simple sugars by the action of dilute acid. The analogy with the products of natural photosynthesis is too close to be passed by without comment.

Although it has not as yet been possible to carry out a complete analysis of this sirup, owing to the difficulty of preparing a sufficiently large amount, interesting information has been gained from the investigation of the sugar sirup obtained by the action of light upon formaldehyde solution. This has been pursued during the last three years. We owe a debt of gratitude to Sir James Irvine for the signal help he has given us in this work. He himself was the first, in association with Doctor Francis, to prove that glucose is one of the substances actually produced. By oxidation of the sugars to the acids by means of bromine, and the crystallization of the salts of these with brucine, cinchonine, and quinine, we have obtained d-gluconic and also d-erythronic acids. This not only confirms Irvine and Francis in their proof of glucose, but it also proves that fructose is formed just as in the living plant. In addition to that, there is produced a mixture of complex acids which afford convincing evidence of the synthesis of complex carbohydrates.

Although it may be thought that the use of formaldehyde as the starting point takes away something from the interest, yet it must be remembered that it makes but little difference whether in actual fact we start from carbonic acid or formaldehyde. Without doubt the first substance, transiently formed in either case, is the same, namely, activated formaldehyde which polymerizes to the sugars.

The similarity between the vital and the laboratory processes is not confined to the fact that the products from the two are the same. Botanists tell us that in the living plant the photosynthesis takes place on a surface, so also is a surface necessary in the laboratory. It has been found possible to compare the quantities of carbohydrates synthesized for equal areas exposed to light in the case of living leaves and the glass vessels of the laboratory. These quantities are about the same. Some plants produce more and other produce less than we are able to synthesize. This similarity may be emphasized, because surely Dame Nature in the living leaf has produced the best machine she could for her purpose of food production for her children of the vegetable kingdom.

There is yet another striking feature which is common to the two, photosynthesis in vivo and in vitro. The light must not be too strong in either, for if it is too strong then harmful results at once supervene. This is due to the poisoning of the surface by the oxygen which is set free. In both cases this poisoning slowly rights itself, and in both the synthesis must not proceed at a greater rate than that of the recovery of the surface from its poisoning.

In fine, so far as we have been able to carry the investigations, the processes in the living plant and in the laboratory show most striking resemblance, not only in the compounds which are formed, but in every feature which is characteristic of either of them.

For my own part I would go further than this, because I believe that these experimental results help us to gain some understanding of the chemistry of life, the chemistry which is so different from that of man's achievements with his test tube, flask, and beaker. Within the confines of vital chemistry reactions take place which are so far outside our own experimental experience that it came to be believed by many that they were under the control of a mysterious force, to which the name of vis vitalis was given. One of these processes has been touched upon to-night, the condensation of the simple sugars, glucose and fructose, to form cane sugar, starch, and inulin. No one has yet succeeded in effecting these syntheses in his laboratory, but it would seem that something of that nature takes place in our photosynthesis. Why then is it that even this step forward has been gained?

The one lesson that we have gained from photosynthesis is that the definitive factor is the very large amount of energy which must be supplied to the carbonic acid before the synthesis of the simple sugars takes place. The means of supplying that energy do not concern the argument. The synthesis proceeds at an energy level which is far higher than is the case in the reactions of ordinary chemistry, and the sugars are formed at that high energy level. I myself believe that the condensation reactions to give the more complex carbohydrates are those which are characteristic of the simple sugars when they exist at the high energy level. The reason why no one has succeeded up till now in inducing these reactions to take place is because no one has hitherto been able to supply the large energy increment necessary.

I myself believe that we find in this the key which unlocks the door of vital chemistry, and that the chemistry of all life is one of high energy, our laboratory experience being confined to the chemistry of low energy. From this viewpoint I see a wondrous vista unfold itself, wherein new understanding, new hopes, and new possibilities reveal themselves. Health and vitality must essentially depend on the high energy level being maintained; any lowering of

82322—30——17

that level will lead to poor health and weak vitality. Knowledge comes to us of the means whereby the high level may be kept unimpaired. The most important sources from which we can absorb high energy are fresh food and ultra-violet light. From the one we learn the necessity of the rapid distribution of our food supply before its high energy is lost, from the other we gain a real understanding of the benefits of ultra-violet light therapy, and, more important still, of the dangers of its misuse. We gain an insight into the chemistry of vitamins, which in the light of our new knowledge reveal themselves as stores of high energy, bottled sunshine so to speak, which yield their energy to restore and maintain the vitality of decadent tissues. A vision thus comes to us of a new chemistry with limits far flung beyond those which constrain our knowledge of to-day, a chemistry which will embrace and coordinate not only the properties of inanimate matter upon this earth, not only the wondrous mechanism of the life of man in health and in disease, but in addition the stupendous marvels of the birth and growth of the worlds outside our own. From those who would decry this as a mere speculation I beg forgiveness, and plead that speculation based on sure experimental fact is the life blood of true scientific research.

NEWLY DISCOVERED CHEMICAL ELEMENTS[1]

By N. M. Bligh, A. R. C. Sc.; A. I. C.

The discovery of a new chemical element can hardly, with scientific knowledge at its present advanced stage, be regarded as a fundamental or epoch-making achievement, nor indeed as one exerting a revolutionary influence on scientific thought as a whole. Nevertheless, the fact that four new elements have been discovered within the last six years, and that they have been found to take their place in the accepted scheme of chemical classification patiently evolved with advancing knowledge, is a matter of considerable satisfaction and importance, and one liable to receive less than its due share of attention and recognition. It happens that occasionally an outstanding scientific discovery is made as the result of chance, as was to some extent the case with Röntgen radiations; or again, a perfectly obvious line of research may, in some inexplicable way, be entirely overlooked over a long period of years. The opportunity is at length recognized by some astute investigator who, following the line of reasoning to its logical conclusion, adds an important result or discovery to the annals of science. As an example of such may be mentioned the isolation of argon and the rare gases of the atmosphere by Rayleigh and Ramsay, who happily developed the work of Cavendish over a century previously. In the majority of cases, however, the achievements of science have been the result of carefully and logically following up a lengthy train of reasoning and research, in which due regard is paid to contemporary advances and modifications of thought, and to a skillful coordination of progressive theory and improved practical technique. In such a category may be placed the recent discoveries of new chemical elements, which it is proposed to consider shortly in the light of the foregoing remarks.

A periodic classification of the known chemical elements had gradually been evolved, in which, however, there were numerous and fully recognized difficulties, not the least of which were certain anomalies and irregularities in the values of the atomic weights of the elements,

[1] Reprinted, with minor changes, by permission of the editor of Scientia, from Scientia, Internationa Review of Scientific Synthesis, vol. XLIII, No. CXII-4, Apr. 1, 1928. Publishers, G. E. Stechert and Co., New York.

and the difficulty of satisfactorily accommodating the rare earth group of metals. Some 16 years ago the science of chemistry, primarily concerned as it is with the elements which form the basis of its studies was, in one important respect, somewhat in the dark, in spite of the periodic table, as regards a matter of primary importance, the total number of elements possible in the scheme of nature. As its name implies the classification was largely guided by the natural recurrence of periodic chemical and physical properties of the elements. Full credit is due to Mendeleef for his remarkable prediction of the "eka" elements, though this depended on analogies suggested by the table, and lacked definite mathematical support such as was to be supplied by the discovery about to be reviewed.

In 1913 a young English scientist, H. G. Moseley, developed a study of the X-ray spectra of the elements in the light of the nuclear theory of the atom advanced in 1911. According to this theory, which is now firmly established, the elements are regarded as consisting of a central positively charged nucleus around which rotate electrons or negative electrical particles, in definite orbits. The successive elements are built up by the addition of an increasing number of orbital electrons accompanied by a more complex development of the nucleus. Starting from hydrogen as unity, having one orbital electron, the elements can be arranged in order of increasing number of orbital electrons, and to each successive element an ordinal number can be assigned. These numbers are termed atomic numbers, and Moseley found a simple numerical relation between these numbers and the frequency of the characteristic line in the X-ray spectrum of any particular element. This epoch-making discovery threw a flood of light on the problem of classifying the elements; atomic weights were now displaced from their position of importance by the still more fundamental atomic numbers, to which the former were found to be approximately proportional. He thus corrected those instances in the periodic table in which it was known that the properties of certain pairs of elements demanded that their positions should be interchanged, a course which could not be reconciled with their arrangement in order of increasing atomic weight. Laborious researches, e. g. in the case of iodine and tellurium, had in the past been conducted under the impression that the accepted atomic weights were inaccurate, and the application of Moseley's discovery cleared away the difficulty.

The attendant difficulty of fractional atomic weights was cleared up at about the same time by the work of Soddy and later Aston on isotopes, which were shown to be elements existing in two or more chemically inseparable forms having the same atomic number, but slightly different atomic weights, the varying proportions of these forms accounting for the fractional atomic weights as determined

chemically. Moseley's relation revealed gaps in the sequence of atomic numbers as determined by spectroscopic data, and these gaps indicated undiscovered elements, agreeing in every case with those predicted by the periodic table, but with the addition of a gap No. 61 among the rare earths. Moreover the relation actually made it possible to calculate in advance the line frequency for the undiscovered elements, and thus provided a most definite means of testing the claim of any newly discovered substance to be regarded as a missing element, and of identifying its nature and position. The definite utility of this principle will be noted in a subsequent section of this survey. At this time (1913–14) gaps in the table indicated missing elements as follows: 43 and 75, analogues of manganese; 61, a rare earth element; 85, a halogen; 87, an alkali metal, and an element 91. Moseley assumed that 72 was filled by celtium, which as will subsequently be seen was not the case. According to the work of Soddy, Hahn, and Meitner (1918), 91 is considered to be filled by a radioactive product, protoactinium, in the actinium series. Moseley's principle served to settle the total number of possible elements with a finality which would never have been possible from a classification built only on analogies and chemical properties; the fact that the latter more indefinite method had overlooked only one element was therefore quite fortuitous. The rare earth group of metals, besides being difficult of separation, contained in itself no conclusive indication of the number of elements which it contained so that Moseley's work settled, in this respect, a troublesome difficulty. It has to be recorded with regret that Moseley met his death at Gallipoli in 1915 at the early age of 28 years. His name has, however, an assured place for all time among the pioneers of scientific progress.

A further stage in the advance of chemical theory has now been surveyed; the disputed difficulties of the periodic scheme have been adjusted in keeping with general developments; an advance has been made, but the work of past decades has not been pulled down to be reconstructed on other lines, rather have the discordant features of this work been gently adjusted to the scheme of nature now more clearly revealed. The next stage shows a further striking development in this direction, and is supplied by Bohr's application of the quantum theory to atomic structure. As yet there was no indication as to whether elements of higher atomic number than uranium (92) might possibly exist, nor was there any developed and supported scheme for the arrangement of electrons in their orbits, nor any fundamental explanation of the well defined periodic groups of elements, or of the existence of the rare earth group. Bohr defined according to quantum principles the orbits in which electrons should be free to move, and evolved a scheme of electron grouping in accordance with the recurrence of periodic properties, in which the rare

earths found a natural and essential place. It was moreover shown that for no a priori reason could uranium be regarded as the final element of the table, but that a continuation of the scheme of electron grouping allowed a theoretical conclusion with an element of atomic number 118. The whole work was supported by, and coordinated with the extensive and weighty evidence of spectroscopic research. The application of Bohr's quantum orbit development scheme made it clear that the element of atomic number 72 could not be a rare earth metal celtium as was originally supposed, but must be an undiscovered higher analogue of zirconium and titanium, likely to exist in ores of these metals, while on the chemical side this was supported by the fact that discordant values of the atomic weight of titanium pointed to the presence of minute traces of an undiscovered analogue. This view was soon brilliantly and completely confirmed by the discovery of hafnium by Coster and Hevesy in zirconium minerals in 1923. The lines in the X-ray spectrum of the new element were found to be well defined; the amount of metal present was quite appreciable and easily separated from the rare earths, all in agreement with theoretical considerations.

Special interest has always been attached to the fact that the periodic table had indicated an undiscovered halogen and an alkali metal. Moseley's scheme confirmed gaps for atomic numbers 85 and 87 corresponding respectively to these elements, and it was somewhat surprising that elements of two such well-defined and distinctive groups should have so long eluded discovery. Among elements of this region, however, a further factor demanded attention, that of radioactivity. Under what conditions might these two elements be reasonably expected to exist? According to their place in the table and also from their atomic numbers, they occupied alternate positions among the most characteristically radioactive elements. Moreover potassium and rubidium had long been known to exhibit a faint radioactivity, although extensive work on them had failed to reveal the presence of any higher analogues to explain this phenomenon. Suggestions were forthcoming in connection therewith; Loring proposed the view that elements of low atomic number may be regarded as having absorbed corpuscular radiation, and an intermediate stage in which an element absorbs radiation and emits it radioactively suggests itself to account for the observed radioactivity of potassium and rubidium, without the apparent accumulation of any radioactive product. On the other hand, Hahn discussed the possibility of 85 and 87 occurring in the subsidiary disintegration series of one of the radioactive elements; but little evidence can be advanced in support of such a view. He and also Hevesy independently tried to detect 87 by a study of the disintegration of mesothorium-2, but in neither case was any conclusive result obtained.

Although superfically it might appear curious that a discovery of note should be made independently and simultaneously, as occasionally happens, by two or more investigators, actually this is by no means remarkable since coordinated practical and theoretical progress is likely to suggest a line of investigation to more than one experimenter, each of whom would refrain from publishing a report of his work until he had amply confirmed it and satisfied himself as to its success. This is well illustrated by subsequent developments in the present sphere of thought, for a marked impetus had been given by Moseley's law to the problem of isolating the remaining elements; the energy of experimenters had been conserved and directed into channels offering reasonable prospect of success; no longer was the search to be pursued under the guidance of only meager principles, effort was not to be dissipated in the attempted isolation of elements which could have no existence. From such considerations is the greatness of Moseley's work realized.

Further gaps in the atomic number sequence of known elements indicated two undiscovered analogues of manganese, numbers 43 and 75. Obviously these should be sought in manganese minerals and could be expected to be present only in extremely minute quantities. At least three groups of investigators are known from published results to have been engaged in this search. The discovery of the two elements was first announced in 1925 by three German chemists, Noddack, Tacke, and Berg as a result of what appeared to be a particularly well-organized piece of research, using platinum ores and the mineral columbite as starting materials. A curious reticence has, however, been observed by these same authors in supporting their results, and in replying to certain criticisms which have been made. Special attention is therefore due to the work of Druce and Loring in England, and Dolejšek and Heyrovský at Prague. The two English workers were engaged in searching for possible elements of higher atomic number than 92, by an examination of the impurities in pure and commercial manganese products, and their X-ray spectrum photographs amply demonstrate and confirm the presence of 75. The method employed consisted in the chemical removal of contaminating heavy metals, and the subjection of the purified product to X-ray analysis. The lines obtained and supported by previous calculation gave definite indication of 75 (dwi-manganese) and in addition there were less definite or less well-defined lines, pointing to 87 (eka-cæsium) the missing alkali metal, and to 85 (eka-iodine) the missing halogen; very faint but inconclusive indication of 93 was also obtained. The fact that the new element was detected even in "pure" manganese sulphate, and had until then escaped observation in so common a material points to the extreme sensitivity of the X-ray analysis method employed, and to a high technique in measuring and interpreting the

spectral lines. Owing to the ease with which the lines are masked by those of contaminating elements, a careful preliminary separation of these elements was necessary, and for the same reason it was found more satisfactory to use "pure" manganese salts than the mineral pyrolusite, even though the former contained a far smaller percentage of the elements sought than the latter commercial ore. This consideration has been quoted to throw some doubt on the spectroscopic evidence of the German workers, whose preliminary separation does not appear to have been sufficiently complete.

Successful support and confirmation of the work of Druce and Loring, as well as further illustration of the use of perfected experimental method, is afforded by the work of the two Czech scientists, who had invented an improved type of electrolysis apparatus termed "the dropping-mercury cathode," for which several important advantages are claimed over the normal type of apparatus. It has a more extensive range of utility, permits work to a much greater degree of precision, and used in conjunction with a device termed "a polarograph," photographs a permanent automatic record in the form of potential curves, of the electrolytic reaction. A study of the curves gives definite indication of the deposition of minute traces of a particular product. By the use of this apparatus, Dolejšek and Heyrovský obtained indications of elements 43 and 75. The latter was confirmed by subsequent X-ray analysis, although evidence of 43 was inconclusive. The materials used and the results obtained agree completely with the work of Druce and Loring and afford valuable independent confirmation and support.

The latest element whose discovery was announced in 1926 was the previously discussed rare-earth metal 61. This has been detected by Harris, Yntema, and Hopkins in America.

The discovery is of special interest as the group of rare-earth elements lying between lanthanum (57) and lutecium (71) is now known to be complete. The group finds a natural place in Bohr's generalized table of elements, and is beautifully explained in his quantum orbit development scheme. As long ago as 1902 Brauner suggested the probability of a missing element between samarium and neodymium as the difference in atomic weight between these two elements is greater than that between their neighbors. He showed also that a study of the periodicity of the hydrides indicated a missing element, according to the scheme CsH. Ba H_2. La H_3. CH_4. Pr H_3. Nd H_2. (XH).

The main difficulty encountered in this group has been the selection of a satisfactory and efficient means of separation, and the method employed was repeated fractional crystallizations of the double magnesium bromate instead of the usual procedure by means of the double magnesium nitrate. The element was confirmed by its absorption spectrum band, which would be masked unless the preliminary separa-

tion had been efficient, hence the importance of selecting a double salt whose solubility should differ appreciably from that of the corresponding salt of associated members of the group. A further confirmation was supplied by the line frequencies obtained from the X-ray spectrum of the product. Since this work has been published an announcement has been made that two Italian scientists have been engaged since 1922 on the problem of detecting and isolating 61 in rare earth minerals, using repeated fractional crystallizations as a means of separation. A thorough examination of the absorption and emission spectrum of the product obtained was in progress when the report of the American chemists appeared. The latter have proposed illinium as the name of the new element. As yet, of course, very little experimental information is available as to the properties of the newly discovered elements. An extensive field of work remains to be covered in devising simpler and improved methods of isolation followed by a detailed study of chemical and physical properties, and possible practical uses and applications. Many of the rarest and most sparsely distributed elements have been found to possess peculiar properties suiting them to special applications. This may similarly be the case with the new substances giving them an importance distinct from their academic interest.

As the whole problem stands at present, the definite indication and discovery of 85 and 87, as well as any of atomic number higher than 92 has still to be accomplished. There can be little doubt that further applications and refinements of the lines of research which have been reviewed above will at an early date bring this important and interesting line of work to a conclusion.

SYNTHETIC PERFUMES[1]

By H. Stanley Redgrove, B. Sc., A. I. C.

The science of chemistry has invaded almost every department of daily life, without the man in the street being at all cognizant of the debt he owes to it. Nor is it realized how many common domestic operations, like cooking a dinner, for example, really consist in causing a number of more or less complicated chemical reactions to take place in the materials employed. By the man in the street and the housewife in the kitchen, "chemicals" are thought to be substances of a nature quite distinct from the things they daily handle and to be chiefly characterized by the possession of a "nasty smell."

There is, indeed, an important difference between the "substances" of the chemist and the raw products of nature, whether of animal, vegetable or mineral origin; and it is very germane to the present study to ask, Wherein does this difference lie? The answer is that chemical substances are "pure." It is true that when we seek to define what is meant by "purity" certain philosophical difficulties crop up, as Ostwald pointed out many years ago, and a long discussion could be entered into on the question, for example, whether solutions are chemical compounds or merely mixtures. For practical purposes, however, "purity" is well understood to denote obedience to the stoichiometric laws. A pure substance, moreover, possesses certain peculiar physical properties, such as a constant boiling point.

No doubt very few chemical substances ordinarily sold as pure are really pure, it being, indeed, extraordinarily difficult to obtain an absolutely pure substance. But chemistry—shall I say?—strives after purity and attains very nearly to it.

On the other hand, nature's products are never pure; they are invariably mixtures, and usually very complex ones, taxing the skill of the analytical chemist to unravel the riddle of their composition.

The application of the term "impure" to the products of nature, it will be understood, carries with it no implication of inferiority,

---

[1] Reprinted by permission from Science Progress, July, 1929.

which the man in the street, borrowing from the use of the word in the moral sphere, attaches to it when it is applied in the domain of material things. As a matter of fact, the "impurities" present in natural products often enhance their value judged from human standpoints. Thus, from a purely chemical point of view, the trace of cholesterol in cod-liver oil is an impurity, the trace of ergosterol an impurity in the cholesterol, and the trace of vitamin D an impurity in the ergosterol. It is just this last impurity, however, which makes cod-liver oil so valuable a preventive of rickets.

I take another illustration more cognate to the subject of synthetic perfumes. The natural perfume material of jasmine has been pretty completely analyzed. It consists mainly of benzyl acetate, a substance easily synthesized from toluene. Now, benzyl acetate has a pleasant odor, reminding one very strongly of that of jasmine flowers; but it is certainly very inferior to this. The natural jasmine odor owes its perfection to the presence of other odorous bodies in association with the benzyl acetate, of which the most important are benzyl alcohol, linalol, linalyl acetate, methyl anthranilate, indole, and a ketonic body called "jasmone."

In the cases of many pleasantly odorous plants, the main constituent of the natural otto is known, as well as the chemical composition of the main "impurities," or, if the word seems a misnomer, let us say "subsidiary substances." Nowadays, it is usually a short step from the discovery of the chemical composition of a substance to its synthetic production, and, in many cases, these substances have been synthetically prepared. One can say, practically as a general rule, that the odor of the main substance gives a crude representation of the natural perfume of a flower. This odor is much improved by the addition of suitable proportions of the subsidiary substances. It still, however, almost invariably falls short of perfection; the reason being that there are further "impurities" present in most minute traces in the natural otto, which chemical analysis has failed to identify, but whose odors play their part in producing the fragrance of the flower.

Two important points emerge; first, the fact that extraordinarily small amounts of certain substances are capable of exciting the sense of smell, and may by their presence or otherwise modify the odor of a perfume; and, secondly, the fact that substances whose odors are unpleasant in a pure state may develop a pleasant fragrance in a state of extreme dilution and play an essential part in improving, from an esthetic point of view, the fragrance of a perfume. Indole, present in the natural otto of the jasmine, is a case in point. Skatole, whose odor is one of the most unpleasant conceivable, affords an even more striking instance, since, used in tiny traces, this substance is distinctly valuable in compounding certain perfumes.

Synthetic perfumes have been criticized as having "coarse" odors. It will be appreciated that this coarseness may arise, not because of any positive property of the preparation, but because it lacks some of the essential "impurities." This explains why the growth of the synthetic perfume industry has not killed the natural perfume industry. Indeed, the effect has been quite the opposite, and the two industries are closely linked together. Chemical research has enabled many of the substances which are responsible for the sweet odors of flowers to be produced at a relatively low cost by synthetic means. Perfect perfumes, however, can not be made with synthetic materials alone; to produce quite satisfactory results a proportion of the necessary "impurities" must be introduced by mixing with the artificial product a small amount of the natural one. The consequent cheapening in the cost of perfumes has resulted in a big increase in the demand for them to the benefit of both sides of the perfume industry.

Some analogies can be drawn between the aniline dye industry and that of synthetic perfumes. We must not, however, fall into the error of the man in the street, who seems to imagine that every chemical product comes from coal-tar. Certainly many synthetic perfume materials do, though some of the most important are made from raw products of a quite different nature.

In this connection the question arises, Where is the line to be drawn between a natural product and an artificial one? Essential oils obtained from plants by steam distillation are classed as natural products; but it would be rash to assume that no chemical changes whatever take place as a result of this operation. In the case, for example, of bitter almonds, it is well known that the essential oil is present in the kernels of the nuts, not as such, but in the form of a glucoside, amygdalin, which has first to be decomposed, the agent for effecting this decomposition, emulsin, being also provided by the kernels.

It seems reasonable, however, to class the products of such operations as steam distillation, and extraction with fats (enfleurage) or with neutral solvents like petroleum ether, as essentially "natural products," those obtained by the two latter processes having indeed special claims to be so considered, as their odors exactly represent those of the flowers from which they are derived.

By means of fractional distillation and, in some cases, by taking advantage of the property possessed by aldehydes of forming crystalline compounds with sodium bi-sulphite, certain of the constituents of essential oils can be isolated in a state of purity. Such products, usually called "natural isolates," are, of course, in no sense "synthetic"; but they may very well be classed with the substances of synthetic origin inasmuch as they are "pure." The oils distilled from certain species of grasses belonging to the genus *Cymbopogon* are

especially useful owing to their cheapness. Thus, from lemon-grass oil, distilled from *C. citratus* and especially *C. flexuosus*, the important alcohol, citral, is isolated. Palmarosa oil, distilled from *C. martini*, constitutes the main source for the isolation of the alcohol, geraniol, one of the constituents of otto of roses. Citronella oil, distilled from *C. nardus*, provides a further source of this alcohol. The aldehyde, citronellal, is also isolated from this oil. Another very important natural isolate is the phenol-ether, eugenol, obtained from oil of cloves. In some instances these "natural isolates" provide starting points for the synthetic production of other important odorous substances, of which examples will be mentioned later.

So far I have written as though the one object of synthetic chemistry, as applied to perfumery, was the production by artificial means of the various constituents of floral ottos, in order that by mixing these together a chemically-exact replica of each and every otto might thereby be obtained. This is certainly one objective; but it by no means exhausts the field of research and practical achievement. In some instances, such as that of otto of roses, chemistry has admirably succeeded in its task, though, even so, the synthetic otto suffers from the imperfection common to all such preparations, and, for the production of a scent which is unmistakably that of the rose, a small proportion of natural material must be added, preferably that obtained by enfleurage, or by the extraction of roses with petroleum ether.

Speaking generally, however, it may be said, in reference to this task, that chemistry, while so far not always successful in solving the problem, has done more than this. In some instances, natural perfume materials have up to date eluded analysis, and their exact chemical composition remains unknown. This is the case with ambergris, an important perfume of animal origin; or, to take an instance of a plant perfume, the exact constitution of the camphoraceous alcohol which is the main constituent of oil of patchouli still remains mysterious.

These are only two instances out of many, and much research remains to be done before it will be possible to say that the perfume of plants has yielded up its last secret. In some cases, however, in which it has not yet been possible to prepare synthetically a substance identical with the natural product, research has ultimated in the discovery of substances resembling this product in odor with a sufficient degree of exactitude to take its place, to a greater or lesser extent, in the art of perfumery.

An important example is provided by musk, the exact chemical composition of which is doubtful, though the main odorous principle would appear to be a methyl-cyclo-penta-decanone. Several synthetic "musks" have been prepared, exhaling the delightful fragrance of this exquisite perfume, which can be obtained far more

cheaply than genuine musk and which have, to a considerable extent, replaced it save in the most costly perfumes. These artificial musks consist of nitro-aromatic compounds and bear no chemical relationship to natural musk whatever. The best is probably that known as "Musk Ambrette," which is a nitrated butyl-meta-cresol-methyl-ether. Other imitation musks are provided by "Musk Ketone" (di-nitro-butyl-meta-xylyl-methyl-ketone) and "Musk Xylene" (tri-nitro-butyl-meta-xylene). The first artificial musk of commercial importance, it is interesting to note, was discovered accidentally by Baur so far back as 1888.

Moreover, in addition to producing imitations of some natural perfume materials and chemically exact replicas of others, chemistry has enriched the art of perfumery, with a whole multitude of odorous substances by means of which not only can the odor of flowers be imitated whose natural ottos it has not been found practicable to extract, but innumerable new nuances of fragrance can be produced.

It would be easy to fill pages with a bare catalogue of the chemical products whose odors render them of value in the making of scent. Many of these are very complex bodies, difficult to prepare and consequently of a costly nature, which are only employed in minute quantities for producing certain particular bouquets and "parfums de fantaisie." It will be more interesting to restrict our attention to some of the commoner synthetic products which are of everyday use in the confection of perfumes.

One of the first synthetic products to be used in perfumery was nitro-benzene, or "oil of mirbane." In the chapter devoted to "Materials used in Perfumery," in his The Book of Perfumes, published in 1867, Rimmel wrote: "The artificial series comprises all the various flavors produced by chemical combinations. Of these the most extensively used in perfumery is the nitro-benzene, usually called mirbane, or artificial essence of almonds. * * * Artificial essences of lemon and cinnamon have also been produced, but have not been brought to sufficient perfection to be available for practical use."

It was not a very auspicious beginning; for, not only is the odor of nitro-benzene very crude, but the substance is poisonous, and does not occur in the essential oil of bitter almonds. However, it was not long before real synthetic oil of bitter almonds, benzaldehyde, made its appearance, and nowadays the use of this substance, which is extensively synthesized from toluene, either by direct oxidation or by chlorination followed by treatment with caustic soda, has very largely replaced the use of the natural oil both for perfumery purposes and for flavoring confectionery, etc., nitro-benzene being only employed to-day for scenting the cheapest and most inferior brands of soap.

Benzyl acetate has already been mentioned as the main constituent of the natural otto of jasmine. This is merely one of an enormous number of synthetically prepared esters which are valuable in perfumery, compounds belonging to this type often having agreeable odors. Certain of the esters of salicylic acid and cinnamic acid are particularly useful. Methyl salicylate is well known under the name of "oil of wintergreen." Amyl salicylate has a very pleasant odor, resembling that of certain species of orchids. It is extensively employed in making artificial orchid and clover perfumes. Some of the esters of cinnamic acid are well adapted for perfuming face powders.

The flavor of vanilla is one universally liked. The odor of the natural product, the dried and cured fruits of *Vanilla planifolia* and allied species of orchids, is almost entirely due to the aldehyde, vanillin, the synthetic production of which is one of the great triumphs of synthetic perfume chemistry. Nowadays, the use of synthetic vanillin has largely replaced that of natural vanilla both as a flavoring agent and, especially, in perfumery. The substance is made by several processes, in England from oil of cloves, on the Continent from guaiacol. Added to a perfume, vanillin gives a quality of sweetness and softness. Moreover, it possesses good fixative powers, serving to retard the evaporation of more volatile ingredients.

The synthesis from clove oil is of particular interest. The essential oil of cloves consists very largely of eugenol, which substance, as already mentioned, can be easily isolated from it. On treatment with caustic potash, eugenol undergoes an isomeric change, yielding iso-eugenol, itself a valuable perfume material, which forms the basis of most artificial carnation scents. On careful oxidation, iso-eugenol passes into vanillin.

Safrol, obtained as a by-product in the separation of camphor from camphor oil, undergoes similar reactions, being converted by treatment with caustic potash into the isomeric iso-safrol, which, when cautiously oxidized, yields the aldehyde, piperonal. This substance, better known as "heliotropine," exhales a delicious odor of heliotrope, in the flowers of which plant it probably occurs accompanied by vanillin and other substances of an odorous character. It is much employed in perfumery, being especially useful on account of its low price.

Another very inexpensive and agreeable artificial perfume material is terpineol, which is manufactured from turpentine. This terpene alcohol has an odor resembling that of the lilac, and, being very resistant to the action of alkalies, is particularly adapted for scenting soaps and hair washes, for which purpose it is extensively employed.

A newer synthetic product, which enables a more exact imitation of the rather sharp odor of lilac blossoms to be obtained, is phenyl-propionic aldehyde.

The odor of new-mown hay is very attractive and characteristic. Synthetic chemistry enables scents exhaling this fragrance to be easily prepared. The odor of new-mown hay is almost entirely due to coumarin, which occurs in *Anthoxanthum odoratum* (sweet vernal grass) and other plants. It is also the chief odorous principle of tonka beans, an extract of which was the chief material at one time used for making perfumes having odors of the new-mown hay type. Nowadays coumarin is prepared synthetically on a large scale, not only for the purpose of making these perfumes, but also for use with many other types of perfume materials as a fixative. It is often mixed with vanillin for the various purposes for which the latter substance is employed.

The synthesis of coumarin from phenol is particularly interesting. The phenol can first be converted into saliclic aldehyde, which yields coumarin by the action of acetic anhydride and sodium acetate. Salicylic aldehyde, itself, has some applications in perfumery. Its odor resembles that of meadow sweet, in which plant it actually occurs.

In Persia, and elsewhere in the East, the odor of the rose is held in the highest esteem, and many readers may be inclined to agree with those easterns who consider otto of roses to afford the finest of all perfumes. Nevertheless, as was recognized years ago, the odor of the otto, obtained by steam distillation, falls short of that of the flower itself. For long the reason for this remained a mystery. But modern chemistry solved the riddle and supplied the means of remedying the defect. The cause is due to the fact that one of the constituents of the natural otto, phenyl ethyl alcohol, is rather soluble in water and is, therefore, washed out of the oil in the process of manufacture, being obtained almost entirely in the rose water. Phenyl ethyl alcohol is now made synthetically by the reduction of esters of phenyl acetic acid; and by its aid very good synthetic rose ottos can be made. Other essential ingredients include the alcohols, geraniol and citronellol. The first, as already mentioned, is isolated from the cheap oils of citronella and palmarosa; the second is made by the reduction of citronellal isolated from the first of these two oils.

Another product obtained from citronella also calls for mention on account of its importance. This is hydroxy-citronellal, a substance which provides a good example of those synthetic products which enable the fragrances of flowers to be very exactly imitated, the extraction of whose natural ottos has not been found practicable. Hydroxy-citronellal is obtained by the hydration of citronellal, and is used for making scents exhaling odors resembling those of lily-of-the-valley (muguet), cyclamen, lilac, and lime-tree blossoms.

There are those who would give pride of place to the sweet violet amongst flowers of pleasant odor. Certainly scents exhaling the fragrance of this lovely little flower, which was so highly esteemed by the ancient Greeks, are exceedingly popular to-day, and can be quite

cheaply obtained, thanks to synthetic chemistry. Except in the case of the most expensive, they contain no perfume material obtained from the violet itself, except, perhaps, a small proportion of the extract of violet leaves, added to give freshness to the odor.

Prior to the discovery of "synthetic violet," the preparation of satisfactory violet perfumes was a very difficult proposition, owing to the fact that the flowers contain only microscopic amounts of perfume material. The odor of the violet is a rare one in nature, orris-root and cassie (*Acacia farnesiana*) being about the only available natural sources from which a tolerable substitute for the violet can be obtained.

An investigation by Tiemann and Krüger of the constitution of the oil of orris-root revealed the fact that its odor is almost entirely due to a ketone, which was christened "irone." These chemists prepared an isomer of this substance by condensing citral with acetone. By heating this substance with dilute sulphuric acid in the presence of a little glycerol, it was hoped that an isomeric change would take place resulting in the formation of irone. An isomeric change did take place; but the product was not irone, since synthesized by a different process. It was a substance, to be named "ionone," with an intense odor of violets, much nearer to that of the flower than the anticipated irone.

Nowadays, ionone is the basic material of all violet perfumes, and is one of the most important synthetic products in the art of perfumery. Actually it is not a chemical individual, but a mixture of two isomers. These can be separated. Their odors are not identical, and each has its several uses in the manufacture of various types of violet scents.

Another very important synthetic product employed in the confection of these and other perfumes is methyl heptine carbonate, which, used in minute quantities, gives that note of "freshness" so characteristic of the fragrance of sweet violets.

The list of synthetic materials used in perfumery could be extended indefinitely. But enough has been said to indicate how important a branch of chemistry the preparation of synthetic perfumes is. The average Englishman, perhaps, is apt to think of perfumery as a rather frivolous subject. Actually, not only great technical skill and artistic sensibility are required for the confection of a fine perfume, but often years of scientific research have gone to the making of it. Every year brings forth new discoveries, more and more new substances, synthetically prepared, being added to the number of materials available for use by the perfume artist. As the mass of material accumulates, it may be hoped that we approach nearer to the solution of the problem of the relation between odor and chemical constitution, and to that of the even more inscrutable puzzle of why certain classes of odors are pleasant, others unpleasant, to the olfactory nerves of human beings.

X-RAYING THE EARTH[1]

By Reginald A. Daly

Reality is never skin-deep. The true nature of the earth and its full wealth of hidden treasures can not be argued from the visible rocks, the rocks upon which we live and out of which we make our living. The face of the earth, with its upstanding continents and depressed ocean deeps, its vast ornament of plateau and mountain chain, is molded by structure and process in hidden depths.

During the nineteenth century the geologists, a mere handful among the world's workers, studied the rocks at the surface, the accessible skin of the globe. They established many principal points in our planet's history. While with the astronomers space was deepening, a million years became for the rock men the unit of time with which to outline earth's dramatic story. Thus, incidentally, the way was opened for the doctrine of organic evolution, demanding hundreds of millions of years, to become secured science rather than mere speculation. The first, main jobs of the geologist were to map the exposures of the rocks at the surface of the earth's skin or "crust," to distinguish the kinds and relative ages of the rocks, and, in general, to gather the many facts that must be accounted for in the final explanation of continent, ocean, plateau, and mountain range. Yet the century closed without having revealed definite origins for these and for many smaller details of the earth's surface and "crust." With increasing clearness geologists became convinced, however, that the main secret of highland and lowland, dry land and deep ocean, Himalaya and Mediterranean, barren rock and ore-bearing rock, must be sought in the invisible, the deep underground of the earth.

The nineteenth century bequeathed to the twentieth an outstanding responsibility—to invent and use new methods of exploring the earth's body far beyond the reach of direct penetration by the geologist's eye or by mine and bore hole. What is the nature of the materials below the visible rocks? How are those materials arranged? What energies are stored in the globe, ready to do geological work when the occasion comes? Where is the earth's body strong, truly

[1] Reprinted by permission from the Harvard Alumni Bulletin, Oct. 18, 1928.

solid, able to bear loads indefinitely? Where is it weak, so weak as to permit movements of the material horizontally and vertically, under the urge of moderate internal pressures?

These questions represent fundamentals of the new earth-lore, already rapidly growing in our own century as investigators continue to employ new methods of research. The problems are largely matters for the physicist, but an unusual kind of physicist, one who makes experiments, like any of his fellows, but keeps thinking of a whole planet. He is an earth physicist, a "geophysicist." The interpretation of messages from the earth's interior demands all the resources of ordinary physics and of extraordinary mathematics. The geophysicist is of a noble company, all of whom are reading messages from the untouchable reality of things. The inwardness of things—atoms, crystals, mountains, planets, stars, nebulas, universes—is the quarry of these hunters of genius and Promethean boldness. The unseen atom has been shown to be no less miraculous than the invisible interior of sun or star. And now, lately, the inner earth as a whole is the gripping subject of research for some of the intellectual giants of our time. To a considerable extent the methods used by all these students of the invisible, the essence of each problem, are in principle the same.

The feature common to most of the productive methods is the use of waves, vibrations, rhythmic motions. From the interior of star or nebula come light waves, heat waves, and whole troops of different unfelt waves. Each of these waves, whatever its nature, radiates through the "ether." With the speed of light, each rushes along lines that are always perpendicular to the front of the wave. These lines are the wave paths or "rays" of the astrophysicist. In the exploration of the universe of stars, he uses light rays, actinic rays, heat rays, and cosmic rays of less familiar kinds. The exquisite internal architecture of crystals is being rapidly revealed with X rays. The atom is becoming understood through its radiant effects and through experimental tests with external rays.

So it is with the new study of the earth; its profounder exploration is possible by means of waves, which may be of either natural or artificial origin. Waves extremely short, as measured from "crest" to "crest," are the X rays, used in learning the atomic architecture of crystals. The somewhat longer waves of light tell us about the nature of stars. The still longer sound waves are now used to give the depths of the invisible ocean floor. "Radio" waves, yet longer, are telling the aerologists much about the nature of the inaccessible, upper atmosphere. For the study of the earth's skin, to the depth of a score of miles or so, the controlled shocks by artificial explosives, which give elastic waves longer than even "radio" waves, are used. Longest of all are the elastic waves set going when the hammer of

the deadly earthquake strikes. Man is learning to harness for his inquiring use the very wrath of the earth; the tremblings of our vibrant globe are used to "X-ray" the deep interior.

When with his hands one bends a stick until it breaks, the sudden snap sends vibrations, often painful, along muscle, bone, and nerve of the arms. The "strain" of the stick is relieved by fracture, and the elastic energy accumulated in the stick during the bending is largely converted into the energy of wave motion. In a somewhat similar way the rocks of the earth's crust have been, and now are being, strained; every day, somewhere, they are snapping and sending out elastic waves from one or more centers. The passage of these waves in the earth we call an earthquake, a seismic disturbance.

Each heavy shock creates waves of several kinds. The kind which travels fastest is like a sound wave; it is propagated by the alternation of compression and rarefaction in the rocks. The particles of the rocks here vibrate to and fro, in the direction of wave motion, that is, along the wave path or wave "ray." Waves of this type, technically called longitudinal waves, can pass from rock into the fluid of ocean, lake, or atmosphere, and if the vibrations are frequent and energetic enough, are heard with the unaided ear. Somewhat slower is a second kind of wave which follows nearly the same path in the rocks, but is distinguished by the fact that now the rock particles vibrate at right angles to the direction of propagation. Waves of the second type, called transverse waves, are analogous to waves of light. Unlike the latter, however, the transverse seismic waves are propagated in solids only and can not pass through a liquid or gas.

These two kinds of waves, longitudinal and transverse, each radiating from the center of shock, correspond after a fashion to the X rays used by the surgeon for exploring the deep inside of the human body. Similarly, the deep inside of the earth is being explored with the two kinds of seismic (earthquake) waves, waves whose diverging paths, or "rays,"plunge right down into the vast interior of the globe and emerge, with their messages, thousands of miles from the center of shock. The longitudinal waves emerge even at the antipodes.

A major earthquake has enormous energy. At and near the center of shock it shatters the works of man and may rupture the very hills and mountain sides. As each wave front spreads into the earth, the intensity of the vibration falls very rapidly, so that not many hundreds of miles from the center the heaviest shock can not be felt by a human being. Much less can he, at the "other side" of the globe, feel the impact of a wave which has plunged to a depth of a thousand miles or more and emerges under his feet.

In order to watch and time accurately each wave, as its ray emerges on the "other side," highly sensitive instruments are used. These wonderful instruments, called seismographs, magnify the motion of the

vibrating rock and give a written record, or "graph," of that motion. They form the main equipment of seismographic stations. The mechanical or photographic record of a distant shock is the seismogram, a kind of hieroglyphic message from the mysterious heart of the planet. Each seismogram from a strong earthquake is a long, complex curve traced up and down on the registering paper of the seismograph. Usually the impulses of the longitudinal and transverse waves are evident to the expert seismologist, but in every case he finds represented much more than these two simple kinds of motion. He sees, in fact, a whole train of waves, which came racing out of the earth, often for much more than an hour after the first impulse was registered. A generation ago, most of the complex message could not be read. Then seismologists bethought themselves of a Rosetta stone.

Observation and theory soon showed that earthquake waves are closely analogous to the familiar waves of sound and light. Like these, the seismic rays are reflected and refracted at surfaces between different kinds of material. Seismic rays, during their passage through the earth, are broken up and dispersed, just as the sun's light is dispersed, in prism or rain drop, to make the glory of the rainbow. Seismic rays are diffracted, just as light rays are diffracted, at the interfaces of contrasted materials. As sound travels faster in water than in air, faster in rock than in either, so seismic waves travel faster in some kinds of rock than in other kinds. Long study of sound and light has led to the discovery of the laws of wave motion, and these have made increasingly clear the meaning of seismograms. The analogy with sound and light is the Rosetta stone.

The discovery of the famous original enabled Napoleon's experts to begin the reading of Egypt's ancient literature. In like manner the seismologists, using the difficult but manageable Greek of modern physics, are beginning the task of making earthquakes tell the nature of the earth's interior and translating into significant speech the hieroglyphics written by the seismograph. It is a long task, requiring high intelligence and the patient accumulation of earthquake data from all parts of the globe, from ocean basin as well as from continent. The work is only just begun; yet the results already obtained are of supreme interest to the philosopher, to the geologist, and to the producer of petroleum, metals, and other materials from the rocks.

For here, too, the man of pure science, the seismologist, "fussing with experiments of no use to anyone," has proved to be another goose that has laid a golden egg. The methods developed by the worker in another "pure" science, seismology, are now, with the help of artificial earthquakes, locating structures that lead to hidden deposits of oil. So, millions are to be saved in the cost of bore holes, and new oil, probably by the hundreds of millions of barrels, will be added to

the world supply. With electrical, magnetic, and gravitational methods—all products of the "unpractical" man of "pure" science—valuable indications of hidden metal-bearing ores are secured, and the expense of exploration by bore holes and shafts is greatly reduced. Seismological methods promise to be adaptable to this kind of detective work. Conquering the difficulties that still remain, future research should make this branch of geophysics, even in the search after metals, pay for its upkeep many times over.

The depths of the ocean are now being quickly and accurately measured by the echo of sound waves from the bottom of the sea. This method, incomparably more rapid and less expensive than the old one by sounding line, is based on a principle fundamental in seismology. With variation of detail, "sonic" sounding, the use of waves reflected from underlying rock, is employed to measure the thickness of glaciers.

Thus, the Hintereisferner glacier of the Alps has recently been proved to be 830 feet thick in the middle. When, with the similar use of explosion shocks and the seismograph, the thickness of the Antarctic and Greenland ice caps are measured, we shall have precious data for guiding thought on the conditions of North America and Europe during the glacial period. Furthermore, we could then estimate how far the sea level was everywhere lowered when the water of these ice caps was abstracted from the ocean and piled up, solid, on the land.

But from depths far greater than glacier floor, ocean floor, or mineral deposit, come the messages from nature's earthquakes. A few illustrations of success in detecting the anatomy of a planet will show the real majesty of the questions and answers that already inspire the all-too-few workers in the new science of geophysics.

One of the outstanding seismological discoveries of recent years is the shelled character of our planet. At the center, and outward to a little more than one-half of its radius, the earth is homogeneous in high degree. This so-called "core" is surrounded by successive shells or layers of material. Each shell, out to a level about 30 miles from the surface, is relatively homogeneous, and its material differs from that of the shell above or below, as well as from the material of the central core. The contacts between the shells and between the deepest shell and the core are technically called "discontinuities."

The discontinuity, or break of material, at the surface of the core is one of the most remarkable of all. It is located at a level about 1,500 miles below the earth's surface, nearly 2,500 miles from its center. A second principal break, found only under the continents and larger islands—and thus representing only parts of a complete earth shell—is situated at the average depth of about 30 miles. Other discontinuities, limiting complete shells of the earth's body,

have been reported at depths of about 75 miles, 250 miles, 750 miles, and 1,100 miles. All of these four breaks require further study. Their estimated depths may be somewhat changed, and other discontinuities may be discovered, but it is already clear in a general way how the earth is constituted—layer on layer. There is good evidence that the core and layers described are composed of matter which increases in density as the depth increases. Hence, so far as the great body of the earth is concerned, it is built stable, and convective overturn with catastrophe to life seems impossible.

The velocity of the longitudinal wave in the earth's core has been measured. The value obtained is appropriate to that of the metallic iron of the meteorites. However, the velocity is lower than that expected if the core iron were crystalline and solid, like the iron of our museum meteorites. The velocity of the longitudinal wave suggests, rather, that the core iron is fluid. In agreement with this conclusion, the slower, transverse wave seems not to be propagated through the core; we have learned that the transverse wave can not persist in a fluid. If further research corroborates this tentative deduction by seismologists, a whole set of new, fascinating problems is opened up.

One question is that of temperature. The pressure on the core iron ranges from 15,000,000 to 50,000,000 pounds to the square inch. Under such colossal pressures the iron can be fluid only on the condition that the temperature of the core is enormously high—at tens of thousands of degrees centigrade. Both pressure and temperature are far beyond the range of the experimental laboratory. The physical state of the core iron can not as yet be described. Is it a liquid, a gas, or iron in a "state" unknown to physics? The conditions of the earth's core are starlike. From their study can physicists of the future tell us something more of the true nature of the stars? If they can, they will be pretty sure, incidentally, to shed new light on the structure and life story of the atoms; for the secret of the star and the secret of the atom are proving to be part of a single problem, the ultimate nature of matter.

Again, if the core is fluid, it is infinitely weak. It can offer no permanent resistance to forces which tend to distort the earth's body. Hence other questions for future research: Is this mobility of the earth's core important in the explanation of the slow upheavings and down-sinkings of great areas of the earth's "crust"? Is the sensitive core involved even in the tumult of mountain building? No one can now tell, but speculate we must, for it is to-day's speculation that leads to to-morrow's science.

The exact nature of the earth shells overlying the core and totaling 1,500 miles in thickness, is another problem for the future. Presumably, the deepest of these shells is a more rigid, because cooler, chemical equivalent of the "fluid" core, but it is not yet clear how

thick this more rigid "iron" may be. The published conclusions as to the composition and precise thicknesses of the still higher shells are uncertain and demand further testing. Yet the principle that the earth is layered seems proved once for all and leads to an apparently inescapable and highly significant conclusion: The shell structure of the earth seems to defy explanation unless it be assumed that our planet was formerly molten. It must have been fluid enough to stratify itself by gravity. The "heavier" materials sank toward the center, the "lighter" materials rose toward the surface, and the whole mass finally arranged itself as layers or shells, with the very dense iron in the central region. It seems necessary to assume primitive fluidity right to the surface, and, further, to assume that the earth was thus fluid after practically all of its substance had been collected in the planet-making process. This general deduction must control future research on the cosmogonic problem—the origin of the earth and its brothers and sisters of the solar system. The earth was born in fervent heat and in the beginning was fervently hot, even at the surface.

While telling us much about the heart of the earth, the seismogram is still more authoritative and eloquent concerning the uppermost layers of the globe. By studying the instrumental records of the reflections, refractions, accelerations, and retardations of earthquake waves, seismologists have found that the continental rocks reach downwards about 30 miles. At that level there is a rather abrupt change to a world-circling shell of a quite different nature. The dominant rock of the continents is granite. According to the facts of geology, as of seismology, the underlying shell or substratum is the heavier, dark-colored basalt, and is apparently the source of this commonest of lavas and the primary seat of all volcanic energies.

The depth of the continental rock, so determined from the writing of the longitudinal and transverse waves on seismographs, is confirmed by study of a different kind of vibrations which come pouring into the station still later than the transverse wave. This third division of a typical seismogram is written by a long train of oscillations, corresponding to what are called surface waves, because they faithfully follow the great curve of the earth's rocky skin. Surface waves are the strongest of all the vibrations recorded by distant earthquakes. They are caused by the reflection of the longitudinal and transverse waves as these, coming from the interior, impinge at low angles upon the contact of rock with ocean water and of rock with the air. That contact acts like the wall of a gigantic whispering gallery. From the character and velocities of the surface waves, expert seismologists have corroborated the evidence, won from the longitudinal and transverse waves, concerning the nature and depth of the continental rock.

But the surface waves inform us also about the kind of rock immediately beneath the deep oceans, whose waters hide from view about two-thirds of the solid surface of the whole earth. The measured velocities of the surface waves show that the earth's skin beneath the deep oceans is crystallized basalt. Thus the material forming an earth shell directly beneath the continents is continuous with, and chemically identical with, the surface rock under the deep sea.

Granite, the principal rock of the continents, is a relatively light rock. Basalt, the essential rock beneath the oceans, is relatively heavy. It is for this reason that the continents float high on the earth's body; they are pressed up by the surrounding, heavy, solid basalt, much as icebergs are pressed up by the denser water of the sea. This is why we have dry land, with its endless importance for man and organic life in general.

Seismology tells us why our home is stable, in spite of mighty forces which tend to level the earth's crust and drown us all. We may confidently expect also that this continued "X-raying" of the outer earth will furnish new information as to the reason why mountains stand so high and are able to keep their heads in the clouds, far above the general level of the continents. And to geophysics, especially to seismology, we look for new help in finding out the conditions for the earth's periodic revolutions when mountain chains were born and sea-bottoms became the pinnacles of the world.

EXTINCTION AND EXTERMINATION [1]

By I. P. Tolmachoff

EXAMPLES OF EXTINCTION AND THEIR USUAL EXPLANATIONS

GENERAL STATEMENT

The extinction of species, genera, families, orders, classes, and even phyla and complete faunas, is a phenomenon well known to paleontologists and biologists, and it is "so common that this has come to be looked upon as the normal course of evolution." [2] Some well-known typical examples of this phenomenon are the extinction of the trilobites at the end of the Paleozoic era, of the ammonites and the gigantic reptiles in the Mesozoic era, of the mammoth at the dawn of human history, and of the sea cow of Bering Strait in the eighteenth century. Although it is so common, extinction is, in its essentials or causes, very little known, or even quite unknown. The examples of extinction just cited have been explained in different ways, but all the explanations, some of which are very detailed, can not withstand criticism.

THE TRILOBITES

The extinction of the trilobites has been attributed to the rise of the cephalopods and the fishlike animals in early Paleozoic time, and of the true fishes in Devonian time.[3] These animals undoubtedly fed on the trilobites and forced them from the dominion of the early seas, ultimately contributing to their complete extinction, but we know that extermination which is brought about solely by the development of a higher or stronger type of life can happen only under exceptional conditions. Usually the smaller and weaker animals have time to make compensating adjustments to avoid extermination. We know, for instance, that the eggs and the young of fish are an easy prey of their many enemies and are destroyed in immense numbers. The chance of survival of an egg of the ling, for example, is 1 in 14,000,000.[4] Yet the ling is not dying out, at least not under natural conditions, but,

[1] Reprinted by permission from the Bulletin of the Geological Society of America, Dec. 30, 1928.
[2] W. R. Gregory, Two views on the origin of man. Science, vol. lxv. No. 1695, p. 602, 1927.
[3] Charles Schuchert, Historical geology, pp. 210 and 324.
[4] R. S. Lull, Organic evolution, p. 103.

like many another fish, it offsets its unavoidable loss by a greater production of eggs. Carnivorous animals and their prey inhabit the same territory for an indefinite time, but a balance in their proportionate numbers is maintained.

As a matter of fact, the organic world of the present time, both of animals and plants, in sea and on land, maintains a balance so perfect that it is brought to our attention only when disturbed by the intervention of man. As between two animals, this balance operates for the benefit of both, for the extermination of the weaker by the stronger would mean the destruction of the source of food of the stronger, resulting in its extermination also. If the Silurian and Devonian fishes could have completely exterminated the trilobites, they would probably have doomed their own existence. Moreover, the extinction of the trilobites was not catastrophic; it was in operation during the Silurian period, when their decline is first noticeable, and it continued through the Devonian and Carboniferous periods, or, speaking in terms of years, through many decades of millions of years—a time long enough to permit the establishment and maintenance of the natural balance. Then, also, the details of their dying out do not support the explanation given. In Silurian time the number of individual trilobites was abundant, but the number of genera and species as compared with those in the Cambrian and Ordovician had been greatly reduced.[5] Moreover, they developed a number of features, such as spines, protuberances, and enlargements of parts, which primarily serve, no doubt, as protective devices,[6] but some of which, by their extreme enlargement, eventually lost their protective value. The enlargement of certain features was common to many extinct animals, and it might be considered a proof of their racial old age.[7] It appears to be a result of the heroic efforts of a race to maintain an organic stock that is losing its vitality.[8] Such efforts were made by the trilobites millions of years before they were serioulsy menaced by their enemies. These peculiar features of organization were not the results of the attack of the fishes, but were due to causes within the trilobites themselves. The trilobites may have disappeared only because as a race they had become old, had lost their vitality, and were unable to establish and maintain the natural balance.

THE MESOZOIC REPTILES

Nor can the extinction of Mesozoic reptiles and gigantic dinosaurs be explained satisfactorily. The animals dominated the earth more completely than do the mammals of to-day, and certainly they had

[5] Charles Schuchert, Historical geology, p. 210.
[6] Idem, p. 271.
[7] Idem, p. 11.
[8] Idem, p. 210.

no enemies outside of their own stock, such as menaced the trilobites. The low mentality of the herbivorous species was confronted with the similar low mentality of their carnivorous enemies. Reference to the simultaneous existence of more intelligent archaic mammals is not significant, for these small, weak animals used their higher intelligence or cunning to protect themselves from their enemies rather than to harm these gigantic reptiles, much less to cause their extinction. In fact, in the opinion of many paleontologists the relations were exactly opposite—that is, the mammalian evolution was handicapped by the domination of reptiles, forming "an overwhelming check against which these small creatures could not contend."[9] In the opinion of Osborn, only the dying out of the large reptiles "prepared the way for the evolution of the mammals."[10] The extinction of the gigantic land reptiles has also been explained as a consequence of a change of climate. The cooling of the climate and the obliteration of their homes in the swamps bordering the inland seas might have had a disastrous effect on the large beasts of Cretaceous time,[11] provided that this change had taken place rapidly; but, in the usual slow course of geological processes, dinosaurs had plenty of time to migrate to more favorable regions or to become adapted to new conditions.

It has been said that the climatic changes that contribute to the extinction of one race at the same time contribute to the evolution of another.[12] It might therefore be supposed that some dinosaurs would have survived, even if the main stock had been completely destroyed. In the opinion of Lull, "one of the most inexplicable of events is the dramatic extinction of this mighty race."[13] Concerning sauropods he writes: "We know of no reason, other than racial old age or a restriction of their peculiar habitat, for their extinction."[14] As has just been explained, the restriction of habitat can not be considered an effective cause. Especially is this true in relation to the reptiles that lived in "the most constant of all organic habitats,"[15] the sea, where climatic conditions would necessarily have been much less noticeable and the animals could have adapted themselves to new conditions more readily than on land. But the Mesozoic reptiles, in the sea as well as on the land, died out completely It may be that their low mentality, which may be compared to that of the present-day fishes, was not so great a handicap as the correspondingly low mentality of the land reptiles.

---

[9] R. S. Lull, Organic evolution, p. 547.
[10] H. F. Osborn, The age of mammals, p. 97.
[11] Charles Schuchert, Historical geology, p. 497.
[12] R. S. Lull, Organic evolution, p. 690.
[13] Idem, p. 531.
[14] Idem, p. 517.
[15] Charles Schuchert, Historical geology, p. 7.

The Mesozoic land reptiles, although differing in all other respects from the trilobites, had many features in common with them that led to extinction. Exaggeration of different parts of the bodily structure; extraordinary size in these reptiles, which attained the possible limit of size for a land animal; inharmonious development of different parts of the body; development of spines surpassing imagination in form, size, and abundance—all these features in the Mesozoic land reptiles, as in the trilobites, point to the senility of a race preceding its extinction. And in the reptiles, as in the trilobites, these features appeared as special devices to meet real needs, but all of them eventually became so much exaggerated as to become handicaps. A good example is that gigantic spiniferous animal the Stegosaurus, which was developed as a special senile side branch and died out without issue.[16] Specialization aiming at some end may become overspecialization. As now used, the term overspecialization generally implies the idea of a tendency toward extinction. Overspecialization leads to extinction, according to Gregory;[17] "extreme specialization may become a cause of extinction," says Osborn.[18] Wieland, writing of the extinction of the dinosaurs, explains it by saying that "the growth forces and the responses to environment were no longer in adjustment,"[19] a condition that is practically equivalent to overspecialization.

We thus reach the same conclusion concerning the Mesozoic reptiles that we reached concerning the trilobites—that before their final extinction they had lost their vital racial force and were unable to maintain that natural balance which was especially necessary to adapt them to a change in environment.

THE AMMONITES

The most mysterious event of this kind is the extinction of the ammonites in the Mesozoic era. They had been declining rapidly during late Triassic time, but they recovered in Liassic time and increased in numbers and in varieties of form so great that in the Jurassic and Cretaceous periods the seas were swarming with them. However, in the Cretaceous period the ammonites suffered complete extinction. The periodic appearance and disappearance of the ammonites has been compared with the corresponding appearance and disappearance of the sea reptiles by which they are supposed to have been exterminated. But with the ammonites as with the trilobites, such an extermination could not have gone on through a number of geological periods, a time long enough for a normal vigorous stock to establish a balance. There are

---

[16] R. S. Lull, Organic evolution, p. 524.

[17] W. K. Gregory, Two views on the origin of man. Science, Vol. LXV, No. 1695, p. 602, 1927.

[18] H. F. Osborn, The age of mammals, p. 34.

[19] G. R. Wieland, Dinosaur extinction. American Naturalist, Vol. LIX, No. 665, pp. 557-565.

also a number of objections to the theory that the ammonites were completely destroyed by reptiles. Many Cretaceous ammonites were deep-sea forms, which were inaccessible to reptiles. It is also worthy of note that the squids, upon which Jurassic reptiles fed,[20] survived the ammonites, although they could have been more easily exterminated than the ammonites.

In the history of the ammonites we see a remarkable phenomenon. The stock declined twice. The first time it was vigorous enough to escape extinction and to develop to a degree unsurpassed in the history of animal life; but the second time, in the Cretaceous period, it reached senility and died out. Overspecialization, such as exaggeration of parts, was expressed in the Cretaceous ammonites no less clearly than in the trilobites and in the Mesozoic reptiles. "Their doom was foreshadowed in the uncoiling, the unnatural twisting of the shells, and the straight baculites."[21] Nothing similar is known of the Triassic ammonites, all of which had the typical ammonite shape, worked out through millions of generations. This race also died out only because of some inner cause or causes. It was unable to establish and keep the natural balance and was doomed to extinction.

Though these examples of the extinction of large ancient groups of animals are, perhaps, the most typical and most widely known, the number of examples of extinction could be increased a hundredfold. In addition to those already cited, there are a few isolated extinct forms having some aberrant structure, which appeared only for a short geological time, and which, being doomed to extinction from the beginning, vanished without descendants. Such were Lyttonia of the brachiopods and Helicoprion of the fishes. These forms, being highly specialized, showed sharp deviation from the standard of their group, which foretold for them "a relatively brief career."[22] At the same time the special features of these aberrant creatures were probably of great biological importance, because, in spite of their short life, some of them were of widespread geographical distribution. However, they left no issue, because a "highly adapted or specialized form becomes stereotyped and incapable of racial change."[23] Their extinction may therefore be parallel to that of the large groups already considered.

The examples here cited include two species that became extinct during the period of human history under fairly well-known conditions, and their extinction therefore has none of the mystery that is connected with the extinction of Paleozoic and Mesozoic forms.

---

[20] Charles Schuchert, Historical geology, p. 476.

[21] Idem, p. 576.

[22] R. S. Lull, Organic evolution, p. 220.

[23] Idem, p. 293.

THE MAMMOTH

The first of these species is the mammoth, which once occupied large areas in Europe, Asia, and North America in numbers probably comparable to those of the American bison. Primitive man, who was well acquainted with the mammoth, has left us true pictures of this animal. Although he used the mammoth for food, it is doubtful whether he was eager to hunt this huge and dangerous beast, especially as he had at his disposal a great variety of game that was more easily obtained. He could occasionally kill a mammoth that had plunged into a bog, fallen into a pit, or had otherwise become entrapped, but, as has often been suggested, he certainly did not hunt it so much as to exterminate it. The extinction of the mammoth has been explained as a result of defects in its organization or of changes in climate. A critical review of these explanations shows that the references to the defects of organization of the mammoth are either erroneous or deal with unimportant features, and explanations of extinction by a change in climate are of little significance, because the mammoth was wonderfully adapted to the physicogeographical conditions, including the climate, under which it lived and died out. The extinction of the mammoth is therefore no less mysterious than the extinction of the trilobites, the ammonites, and the Mesozoic reptiles. But the mammoth, like all animals doomed to extinction, became highly specialized or even overspecialized. The extreme complexity of the teeth of the Siberian mammoth,[24] which has been considered an adaptation to the harsh vegetation of the north, but which was probably an expression of extreme specialization, was accompanied by peculiarly constructed tusks and by 4-toed feet. The feet of other elephants are 5-toed, although in some species, especially in the African elephant, they show a tendency toward the reduction of the lateral digits of the hind foot.[25] During its long existence in an Arctic climate the mammoth also developed a number of features as a protection against cold. Each of these features is highly specialized or even overspecialized. It may therefore be suggested that the mammoth, having, like other extinct animals lost racial vitality, was doomed to extinction, owing to overspecialization, and was therefore unable to maintain the natural balance.

STELLER'S SEA COW

Another example of the recent extinction of a species is seen in the history of Steller's sea cow. Discovered living near the shores of islands in Bering Strait by the Bering expedition in 1741, it was completely exterminated during the next few years.[26] It was extermi-

[24] R. S. Lull, Organic evolution, p. 602.
[25] Idem, p. 580.
[26] A. Th. Middendorff, Reise in den äussersten Norden and osten Sibiriens, Bd. IV, Th. 2, S. 841.

nated by man in a very short time, we might say instantaneously, in a catastrophic way. But even as to this animal we are not quite certain as to the real cause of extinction. It inhabited a small area in numbers that apparently formed a remnant of a species that was once abundant. Its propagation had doubtless been greatly impaired and its body was highly specialized with respect to its environment. It was probably already well advanced toward extinction and the Bering expedition only accelerated its end.

EXTINCTION AND EXTERMINATION DISTINGUISHED

In connection with the extinction of Steller's sea cow, exterminated by man, let us consider the difference between extinction and extermination. The words are often used indiscriminately, the lack of discrimination causing some confusion in the consideration of this question. Extermination is the killing by man, by other animals, or by a change of climate, flood, or any other outside agent—all directly or indirectly affecting an individual or group of individuals. Extinction is a dying out; and the word applies to a species or to any other larger or smaller taxonomic group. If the word is used in referring to a group of individuals, as to a number of animals of the same species living in a forest, on an island, or in some other restricted area, its meaning would be limited geographically. With many species extinction is the passive reaction of the organism against several different destructive agents, and the extinction of the species may be due to extermination. Some papers on extinction deal only with extermination. A good example is a paper by Osborn, "The causes of extinction of mammalia,"[27] in which the numerous possible causes of extermination of mammals are considered in great detail. The difference between these phenomena has been emphasized in an article by Smith Woodward. In his words, "Local extinction, or the disappearance of a group of restricted geographical range, may be explained by accidents of many kinds, but contemporaneous universal extinction of widely spread groups, which are apparently not affected by any new competitors, is not so easily understood."[28] He does not try to explain "the universal extinction" except in connection with the old age of a race. His "local extinction" and "general extinction" correspond exactly to extermination and extinction as both these words have been used in the present paper.

Extermination that might affect two species, one a prolific group and the other a group already in process of extinction, if it were to go on incessantly, would produce the same result in both species—both would become extinct. If, however, extermination were checked, the

[27] American Naturalist, Vol. xl, pp. 769-795, 829-859, 1906.

[28] A. Smith Woodward, Address of the President to the Geological Section of the British Association for the Advancement of Science. Science, Vol. xxx, p. 327, 1909.

first species would be able to recover and make good its losses, whereas the second would continue to die out and sooner or later would become extinct. The fur seals of Bering Sea were nearly exterminated through reckless hunting by American, Japanese, and Russian trappers. A special convention held by representatives of the three countries resulted in the formulation of laws that restricted the slaughter of this valuable animal and checked its extermination.

A contrast to the preservation of the fur seal is seen in the fate of the bison in Russia. A last remnant, a herd of a few hundred of these animals, which had been once widely distributed in eastern Europe, lived in the southwestern part of European Russia, in the so-called Beloveshskaya Pushcha, a virgin forest covering some hundred of square miles. The animals were living in a reservation protected by strict legal regulations and were seldom disturbed, for the Pushcha was a wilderness and could be visited only by special permission, which was difficult to obtain. The animals were unmolested except during the rare hunting trips of the Czar, when few were killed. Further protection was given them against wild carnivorous animals and against hunger in winter, when supplies of hay were distributed to different parts of the forest. In spite of all these precautions the animals were slowly dying out, not only because of a gradual decrease in their number, but because the percentage of bulls among the young was abnormally large. Their complete extinction, which was approaching, was accelerated during the World War by the wild hunts of German officers at the time of the German occupation of this part of Russia. Some Russian scientists suppose that their extinction is due to too close interbreeding among animals of the same herd, but it may have been a result of natural senility of the race. The number of bison of eastern Europe was reduced to a single herd and the extinction of the animals was incessantly and surely approaching in spite of all the protection given them.

A sharp contrast to the fate of the Russian bison is seen in that of the American bison, a close relative of the European, which was nearly exterminated by the white man after he invaded North America. A few hundred of these animals that had found protection in reservations of the United States and Canada proved to be very prolific. They have increased to a number so large that it has become necessary to kill many of them to avoid overcrowding the reservations. The extinction of these animals by extermination has been easily stopped by the protection given them. The difference between the fate of the American and the European bison is due to the fact that the American bison was of a prolific race; its vital forces are preserved, even though it suffered closer interbreeding than the European bison, which belonged to a race that was already in process of extinction.

A study of the extinction of animals in historical and recent time affords us no better understanding of this phenomenon than the study of the extinction of animals in Paleozoic and Mesozoic time. Some animals are doomed to destruction as a race; others of the same kind are capable of prolific propagation, although there is no apparent difference in their organization or in their environment.

In the forms considered above, old and new alike, we find high specialization in all species or groups of species which are doomed to extinction. Extinction is evidently dependent on some inner deficiency, although it is usually accompanied by high perfection in certain features—by far-reaching specialization.

INDIVIDUAL AND RACIAL INTERESTS

GENERAL STATEMENT

The preservation of an individual and of a species does not invariably follow the same law or principle. We can even say that the interest of the individual and of the species may be directly opposite. The mechanism of evolution insures the extermination of the weak and the poorly adapted, and in animal breeding a rational elimination may be applied with good results to the race. In fish culture, for example, a few pike are usually placed in the pool at a certain time to devour the undersized fish and to create better feeding conditions for the larger and stronger fish. This practice is followed in the interest of the species.

On the other hand, some action that might be favorable to the individual may be destructive to the race. Birth control, for example, is practiced in the interest of the individual, but if it should be applied widely and constantly, it would bring about the extinction of the human race. The destruction of the race would thus result from action undertaken for the benefit of the individual.

INSTINCT OF SELF-PRESERVATION CONTROLLING THE INTERESTS OF THE INDIVIDUAL

The instinct of self-preservation protects an organism against extermination; but parental and sexual instincts care for the race. The violation of the law of self-preservation may mean suffering varying in intensity according to the degree of violation and in its extreme form (suicide) causing death. Against this suffering and possible death every living creature maintains a struggle thoughout its life, a struggle supported and directed by the instinct of self-preservation, which has been developed during countless generations. The violation of this instinct by self-destruction is rare among the lower animals and it is abnormal among human beings, although the instinct of self-preservation may be sacrificed to the stronger tendency arising from the instinct governing the preservation of the species or the race.

PARENTAL AND SEXUAL INSTINCTS WORK FOR THE PRESERVATION OF THE RACE

General statement.—The desire to preserve the species does not appeal to the individual so strongly as the instinct of self-preservation, because its effect lies beyond the period of individual existence and covers unborn generations. Reaction against events endangering a species is therefore not so immediate as reaction against events endangering the individual. The instincts governing the preservation of species are therefore less comprehensible and may seem mysterious. The parental and sexual instincts insure the preservation of a race, and although they differ in different groups of animals and among different individuals of the same group, they are usually more powerful than the instinct of self-preservation.

Parental instinct.—The parental instinct is developed to extreme perfection in the insects. A large part of the life of many adult insects is devoted to work done in the interest of future generations, such as that of seeking protected places in which to raise the young and providing them food. No breeder has so many cares for his stock nor plans so carefully for future conditions. This instinct is also possessed by fishes, whose well-known seasonal migrations from the sea into rivers and upstream, in spite of rapids and waterfalls, are made for no other purpose than to find good breeding grounds for the next generation. So devoted are they to their task that, in spite of their loss of strength in traveling upstream, they do not stop for food, but completely disregard the instinct of self-preservation, and after having accomplished their aim they perish.

The parental instinct appears to be the very foundation of human society. Such institutions as marriage and the family, on which human society is based, have originated for the sake of future generations. Care for children is still a leading motive in the life of communities, among barbarous tribes as well as among highly cultured nations. With rare exceptions, fathers and mothers are ready to sacrifice their lives for the sake of their endangered children. We thus observe that in human society, just as among fishes and insects, the instinct of self-preservation retreats before the parental instinct.

Sexual instinct.—The sexual instinct among all animals is stronger and more mysterious than the parental instinct. The most striking examples are found among the insects, in which the sexual instinct manifests itself in different and in extremely peculiar forms. Among the bees, for example, the sexual instinct serves exclusively the interests of the community. The male and female bee mate only once, and after the mating the male, being mortally mutilated, dies immediately. The other male bees, the drones, whose possible usefulness to the community is ended by that mating, are tolerated only until the

honey harvest season is nearly at is end, and are then mercilessly killed and cast out by the workers. This hecatomb after the act of reproduction and the later care of the eggs and young by the asexual bees involves complete neglect of individual interests, the sexual instinct becoming a communal affair.

Among spiders the female may attack and devour the male after mating. The male, knowing well his possible fate, is not deterred from mating by the instinct of self-preservation. During mating the female mantis often gnaws the head of the male, who neither offers real resistance nor tries to escape. Among copepoda some males are so different from the females that it is difficult to identify them as members of the same species. They are much smaller and, roughly speaking, consist of a sack filled with sperms, living as a parasite attached to the reproductive organs of the female. Here the individuality of the male is completely sacrified to sexual interests and reproduction.

Among the higher animals, human beings not excepted, the sexual instinct is very strong, although its effects are not always recognized or understood. The sexual instinct is a powerful motive of many human actions. Three-fourths or more of the crimes committed and a large percentage of the suicides are directly or indirectly chargeable to it. The life of an individual is often sacrificed to what is termed sex appeal. History has preserved many stories of beautiful queens who had their temporary lovers put to death. Some of these men realized that they would pay with their lives for a short felicity; but, led by the sex appeal, they were willing to ignore the instinct of self-preservation. When a present-day suitor expresses his willingness to pay for sexual favors with his life, he unconsciously reverts to conditions in former days, when such an affair was serious and might have grave consequences.

These few examples, which could be multiplied indefinitely, show that not everything which is beneficial or pernicious for the individual is such for the preservation of the race, and vice versa. The importance of this fact has never been sufficiently appreciated. Most paleontologists and biologists who have attempted to explain the extinction of a race have sought causes that affect the individual and have cited these causes in explaining the extinction of a species. It is not surprising that such explanations could not withstand criticism and were usually complete failures.

INDIVIDUAL AND RACIAL LIFE

METABOLISM CONTROLLING THE EXISTENCE OF THE ORGANISM

The existence of an individual is dependent on its ability to find food and transform it into body tissues by means of very complicated processes known as metabolism. If the metabolism of an animal is

wrong, it becomes sick, and if the defect is not corrected the animal dies. Every individual, after living for a time that differs greatly for different animals, but that is of more or less the same duration for every species, will unavoidably be affected by defects of metabolism and will die a so-called natural death.

POWER OF REPRODUCTION CONTROLLING THE PRESERVATION OF A RACE

The preservation of a race is dependent on the ability of the organisms composing it to reproduce. Usually this ability is conjoined with the physical development of the individual, which may be divided into three stages. The first stage is the period of greatest growth, when the income of the body is much greater than its expenditure. The stage continues until physical maturity is reached, when some kind of equilibrium between income and expenditure is established, which is maintained throughout the reproductive period. With the passing of the period of reproduction metabolism decreases and the individual gradually loses vitality. This general statement may not be correct for every organism or race, but as the expression of a general principle it may be sufficiently correct.

DECREASE OF REPRODUCTION IN HIGHER AND MORE SPECIALIZED ANIMALS

The relation between reproduction and individual life is not invariably so simple. For no apparent reason a strong, healthy individual may be incapable of reproduction. The power of reproduction also may not be completely lost; it may be only decreased, as it is when the number of births is small, or when the percentage of male births in a species or race is much higher than that of female births. This phenomenon may be considered the beginning of sterility. We do not know the real cause of sterility that is not produced by some evident abnormality. It has been suggested that insanity provokes sterility in the fourth generation. Too close interbreeding may gradually develop into sterility, and if the stock is not reinvigorated with new blood it will bring about the complete extinction of a race, though the correctness of this statement has been questioned or denied by some biologists. It has been observed that in the first generation interbreeding gives offspring of high grade. In this way a breed of setters of high quality, but of short longevity, was obtained. The breed began to die out so quickly that the breeder witnessed the gradual extinction of his product.

Sterility, even in its first stage, in no way shows a low degree of advancement of a species. Indeed, prolification may decrease with advancement, either through a diminishing number of offspring or an increasing period of gestation and maturity. Man has the rather

doubtful distinction of being one of the least prolific of animals. It is also suggested that the higher human races are less prolific than the lower ones, and that a higher standard of living is usually accompanied by a lower birth rate, which is not compensated by a correspondingly low death rate. The very common dying out of low human races that bear only a few children does not invalidate this statement, because this phenomenon is due to certain special causes. The prolification of the lower animals is enormous. According to Huxley's estimate, the descendants of a single green fly, if all of them survived and multiplied, would at the end of one summer outnumber the population of China. Common house flies would in the same time occupy a space of about a quarter of a million cubic feet, allowing 200,000 to a cubic foot.[29] These examples are by no means extreme. In comparison with them we find an example no less striking—that of the elephant, which begins to breed at the age of thirty years and has a period of gestation of nearly two years.

We do not know why high specialization and perfect adaptation to certain conditions is accompanied by complete sterility or by a decrease of fecundity, which is, probably, the first stage of sterility. We can only suggest that sterility has developed slowly and gradually, and that in the animal kingdom it begins with unconscious weakening of the sexual instinct. Animals whose physical and psychic forces are given over to a certain aim, such as the achievement of a certain adaptation, have not the same energy to expend in perpetuating the race as those whose energies are not thus expended. In succeeding generations this transfer of energy could gradually provoke a degradation of the reproductive organs, very slight at first, by dulling the sexual instinct. These changes would be going on simultaneously with the final and fatal result, the loss of the power of reproduction.

DECREASE OF REPRODUCTION IN HIGHLY SPECIALIZED PLANTS

Unhappily, we are not able to discover why sterility affects some individuals that are apparently in perfect physical condition. In the solution of this problem we get much more information from the study of plants. A great number of highly specialized cultivated plants seldom or never produce seeds and have to be propagated by cuttings. A well-known example is the garden rose. Few cultivated varieties of the banana[30] or the sugar cane produce seed.[31] The sweet potato (*Batatus edulis*) has been preserved only through cultivation.[32] Through cultivation, also, the common potato (*Solanum tuberosum*) is gradually losing its power to produce seed. Bailey

[29] R. S. Lull, Organic evolution, p. 104.
[30] A. De Candolle, Origin of cultivated plants, p. 307.
[31] Idem, p. 156.
[32] Idem, p. 33.

says: "In the potato, as tuber production has increased, seed production has decreased. Now potatoes do not produce bolls as freely as they did years ago." [33] So-called seedless fruits belong to the same category. Some of these highly specialized plants, if left without the attention of a gardener, would perhaps restore their lost power of producing seed, and they would at the same time lose their acquired artificial qualities; but most of them would soon become extinct, if it were not for the intervention of man.

OBSERVATIONS ON PLANTS APPLIED TO ANIMALS

The observation of highly specialized plants helps us to explain tentatively the alterations that are going on in highly specialized animals and that decrease their productivity. The parts affected are the genital organs, or, to speak more correctly, perhaps, the genital glands, the secretions of which may more or less decrease or cease entirely, like the production of seed ceases in highly specialized plants. Animals as individuals would not be harmed by this loss; they might even be benefited by the transfer of energy to other parts of the body, but for the preservation of a race the loss would be fatal. On the other hand, the specialization of certain parts of the animal body to form reproductive or genital organs diminishes prolification. In the lower organisms reproduction goes on by the fission of the whole body. In the Infusoria such fission may even be produced mechanically by skillful dissection. But the evolution of the animal kingdom is paralleled by a decrease in prolification. Most of the members of a colony of Coelenterata may lose entirely the power of reproduction, which has become a function of certain specialized individuals. In other animals reproduction through fission occurs only by budding in certain parts of the body. The origin of the genital glands of the higher animals may be traced to budding, but in greatly modified and highly specialized form, a form that is easily subject to the influence of many exterior and interior agencies. All the variations in the reproduction of different animals and in their fertility must be considered in connection with the structure, function, and alteration of these important parts of every animal that has a somewhat high systematic position.

By all these considerations we are able not only to explain extinction brought about by the great specialization and accompanying sterility of organisms, but to understand the origin of those peculiar structures that paleontologists consider indications of the old age of a race. Some kinds of specialization that affect the reproductive powers of a race may not cause immediate sterility, but may produce

[33] L. H. Bailey, Plant-breeding, p. 225. The writer feels greatly indebted to Dr. O. E. Jennings for all the information concerning cultivated plants.

a gradual decrease in prolification. Such specialization releases energy, which is used to achieve further specialization and to increase structural variability, or to develop structures that may be beyond present needs. The energy that had been devoted to reproduction seems to have been diverted to the multiplication of alterations of bodily structure. When we consider the spines on the valves of a Productus; the rich ornamentation, the ribs, spines, and tubercles on the shells of ammonites; the peculiar armor and forbidding spines of the Stegosaurus; the antlers of the extinct great Irish stag; the gigantic but not correspondingly advantageous size of the Diplodocus, and other similar forms, we can only conclude that all these extremely developed features represent an unnecessary excess of structure and waste of energy. Extravagance of structure decreases the reproductive ability of a race and diminishes its resistance to extermination, although at the same time the race may appear to be well prepared for the struggle for existence—a fact that makes its extinction inexplicable and mysterious.

Complete sterility is not the only condition determining the extinction of a race, and it was doubtless attained only in a few extinct races, but partial sterility, or the decrease of reproductive power beyond certain limits, is probably the axis on which the whole process of extinction revolves and is, perhaps, the main or only cause of this mysterious phenomenon.

The relation between the extinction of a race and its fertility has been very little considered by naturalists. Merriam suggests [34] that diminished reproduction induced by low temperature would be a barrier to the geographical distribution of a certain race and would contribute to its extinction; but if the race had preserved its structural flexibility—in other words, if it had not been overspecialized and its productive ability were normal—it would gradually become adapted to new conditions and survive them.

HIGH SPECIALIZATION AND INCREASED FERTILITY OF PARASITES

We know of only one class of animals, the parasites, in which close adaptation to the immediate environment, causing an unavoidably great overspecialization, has been accompanied by increased fertility. However, this apparent exception only supports the view here advanced. In parasites the specialization is degenerative. They lose the organs of locomotion, and the special senses and the nervous system accordingly degenerates. The external skeleton becomes simpler or is entirely lost. Reduction of the vegetative organs, such as those of respiration and circulation, of the alimentary canal, and of the digestive glands is common.[35] These organs therefore be-

[34] H. F. Osborn, The age of mammals, p. 504.

[35] R. S. Lull, Organic evolution, p. 266.

come of very little use, and the energy that is used by other animals in the specialization of bodily parts is in parasites freed and given over to reproduction, resulting in the preservation of the race. Consequently the genital organs of parasites are greatly enlarged, and all parasites are very prolific.

CONCLUSIONS

Owing to extinction, the normal course of evolution has been interrupted innumerable times. There is no line of evolution to which this statement would not apply. Races have been preserved not by means of their most brilliant representatives, for great achievements cause some deficiency of vital racial force, but rather through mediocre individuals. We are even able to establish an empiric law that "the upwelling of future organic rulers begins in unobtrusive small forms," [36] or, as expressed by Cope, in the "survival of the unspecialized," because, as he states, the highly developed or greatly specialized types of one geologic period are not the parents of the types of succeeding periods.[37]

Especially important and interesting in this respect are those persistent types that have gone through a number of geological periods without great alterations in structure. Their evolution has been arrested,[38] and in recompense they have received a longevity that seems to approach immortality.

---

[36] Charles Schuchert, Historical geology, p. 449.

[37] Idem, p. 450.

[38] Rudolph Ruedemann, Paleontology of arrested evolution. New York State Museum Bulletin, No. 196, pp. 107–134, 1918.

THE GULF STREAM AND ITS PROBLEMS[1]

By H. A. Marmer

U. S. Coast and Geodetic Survey

Maury's The Physical Geography of the Sea, which appeared in 1855, is frequently referred to as the first textbook of modern oceanography. In that work the author devotes the first chapter to the Gulf Stream, introducing it thus:

> There is a river in the ocean. In the severest droughts it never fails, and in the mightiest floods it never overflows. Its banks and its bottom are of cold water, while its current is of warm. The Gulf of Mexico is its fountain, and its mouth is in the Arctic Seas. It is the Gulf Stream. There is in the world no other such majestic flow of waters. Its current is more rapid than the Mississippi or the Amazon.[2]

Even in matters scientific, customs change. It is altogether unlikely that an oceanographer nowadays would speak of the Gulf Stream as rhetorically as did Maury. The magnitude of this current, however, is such that even later students make use of superlatives in describing it. The most comprehensive investigation of the Gulf Stream was carried out between the years 1885 and 1889 by Lieut. (later Rear Admiral) J. E. Pillsbury, United States Navy, while attached to the Coast and Geodetic Survey. And when he came to write up the results of his observations and studies he described it as "the grandest and most mighty * * * terrestrial phenomenon."[3]

Of all the currents that make up the systems of oceanic circulation, the Gulf Stream has received the greatest amount of study and is the best known. Its discovery, or more accurately the first notice on record, came shortly after the discovery of the new world. Early in March of 1513, Ponce de Leon set sail from Porto Rico with three ships on a voyage of exploration. Setting a northwesterly course the expedition discovered Florida, a landing being made on the eastern coast somewhere in the general vicinity of Cape Canaveral. Sailing southerly then they encountered on April 22, as related in a chronicle of the expedition, "a current such that, although they had a great

[1] Reprinted by permission from the Geographical Review, July, 1929.

[2] M. F. Maury: The Physical Geography of the Sea, p. 25, New York, 1855.

[3] J. E. Pillsbury: The Gulf Stream: Methods of the Investigation, and Results of the Research, Appendix No. 10 of Rep. of the Supt. of the Coast and Geodetic Survey for 1890, pp. 459–620, Washington, D. C., 1891; reference on p. 472.

wind, they could not proceed forward, but backward, and it seemed that they were proceeding well; and in the end it was known that it was in such wise the current which was more powerful than the wind." [4] Thus was the Gulf Stream first noted.

Apparently the Spaniards soon learned that this northerly flowing current was not merely a local current but one of wide extent; for six years later, when Antonio de Alaminos set out for Spain from Vera Cruz, he sailed northward with the Gulf Stream for a number of days before turning east toward Europe. This same Alaminos was pilot of Ponce de Leon's expedition of 1513 when the Gulf Stream was first noted. It is therefore quite proper to credit the discovery of the Gulf Stream to Alaminos.

EARLIEST GULF STREAM CHART

For two and a half centuries following its discovery the growth of knowledge regarding the Gulf Stream was slow. The story is told in detail by Kohl [5] and more briefly by Pillsbury. During this period, to be sure, the mariner, and more especially the whaler, became acquainted with the Gulf Stream throughout the greater part of its course. Much of this information, however, was kept as a professional secret, and it was not until after the middle of the eighteenth century that the course of the current was depicted on a chart. The story of how this came about is not without interest, especially as it illustrates nicely the effect of the Gulf Stream on navigation.

About 1770, complaint was made to the London officials that the English packets which came to New York took about two weeks longer in crossing than did the Rhode Island merchant ships which put in at Naragansett Bay ports. Benjamin Franklin, being in London at the time, was consulted about the matter. To quote his own words:

> It appearing strange to me that there should be such a difference between two places, scarce a day's run asunder * * * I could not but think the fact misunderstood or misrepresented. There happened then to be in London a Nantucket sea captain of my acquaintance, to whom I communicated the affair. He told me he believed the fact might be true; but the difference was owing to this, that the Rhode Island captains were acquainted with the Gulf Stream, which those of the English packets were not * * * When the winds are but light, he added, they are carried back by the current more than they are forwarded by the wind * * * I then observed that it was a pity no notice was taken of this current upon the charts, and requested him to mark it out for me, which he readily complied with, adding directions for avoiding it in sailing from Europe to North America.[6]

---

[4] L. D. Scisco: The Track of Ponce de Leon in 1513, Bull. Amer. Geogr. Soc., Vol. 45, pp. 721–735, 1913; reference on p. 725.

[5] J. G. Kohl: Geschichte des Golfstroms und seiner Erforschung von den ältesten Zeiten bis auf den grossen amerikanischen Bürgerkrieg, pp. 1–114, Bremen, 1868.

[6] A letter from Dr. Benjamin Franklin, to Mr. Alphonsus le Roy, Member of Several Academies, at Paris: Containing Sundry Maritime Observations, Trans. Amer. Philos. Soc., Vol. 2, pp. 294–329, 1786; reference on pp. 314–315.

Franklin goes on to relate that he had the information engraved "on the old chart of the Atlantic, at Mount and Page's, Tower-hill; and copies were sent down to Falmouth for the captains of the packets who slighted it however; but it is since printed in France, of which edition I hereto annex a copy." (Fig. 1.)

As evidenced by Franklin's letter in the Transactions of the American Philosophical Society, the Gulf Stream towards the end of the eighteenth century became a subject of scientific investigation and discussion. Franklin himself made observations on the temperature of the sea water during a number of voyages and noted with regard to the Gulf Stream "that it is always warmer than the sea on each side of it." By the middle of the nineteenth century, when systematic

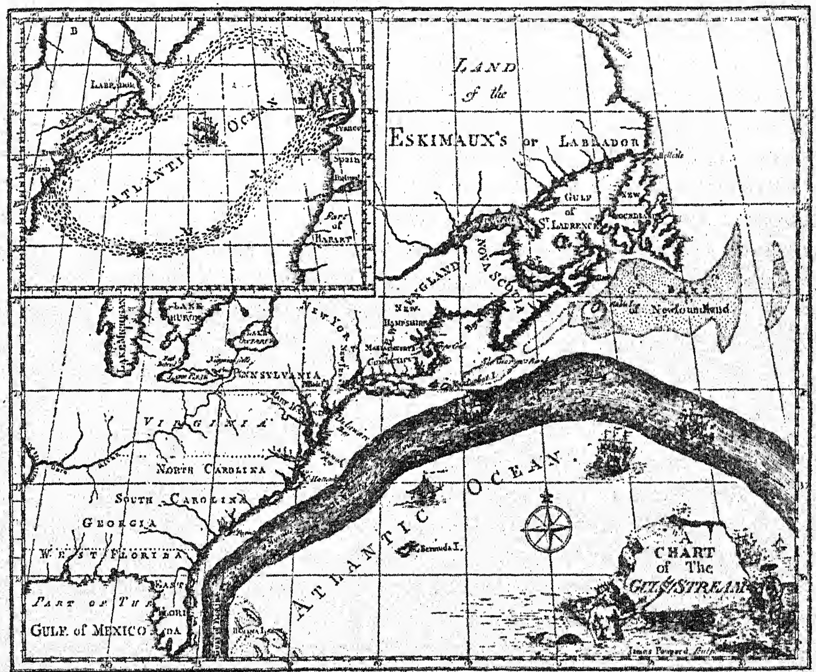


FIGURE 1.—Franklin's chart of the Gulf Stream

observations were begun, a fund of information had been gathered from navigators' logs and from the observations of scientifically minded travelers.

SYSTEMATIC OBSERVATIONS

Systematic observations in the Gulf Stream were begun in 1845 by the Coast Survey under the superintendency of Alexander Dallas Bache, a great grandson of Franklin. At different times up to the year 1889 specially equipped vessels were detailed for the work, the results being published as appendixes to the annual reports of the Superintendent of the Coast and Geodetic Survey, the last one being

that by Pillsbury cited in footnote 3. In passing, it is to be noted that this systematic work was confined almost wholly to the Gulf Stream along the coast of the United States.

The published material on the Gulf Stream is extensive. Here it will be sufficient to direct attention only to the more authoritative recent work. Krümmel, in what is still the standard treatise on oceanography,[7] gives a brief but critical summary of the hydrographic features of the Gulf Stream as developed to the end of the first decade of the present century, and Schott [8] brings the discussion up to the present time. And, while dealing with but a restricted part of the Gulf Stream, Wüst's study [9] should be mentioned here because it represents a successful attempt to correlate and elucidate the phenomena involved in the Gulf Stream by means of mathematical, or more accurately perhaps, dynamical methods.

It is customary to trace the last remnant of the Gulf Stream into the Arctic waters north of Norway. From its place of origin in the Gulf of Mexico, therefore, this current traverses a route of more than 6,000 miles. But it is not as a "river in the ocean" that it manifests itself throughout its course. The phenomena presented are much more involved, and the stream is to be regarded rather as a complex system of currents than as a single current. We may arrive at an understanding of the nature of the forces and factors involved by a brief consideration of its characteristics in the region in which it has been most carefully studied.

THE CURRENT IN THE STRAITS OF FLORIDA

It is in its first reach, through the Straits of Florida, that the characterists of the Gulf Stream are most marked. Here its waters have the highest temperature and salinity and the swiftest flow. And because it is here confined within a restricted channel it lends itself more readily to investigation. Observations have here been made across a number of sections; and with this stretch, too, Wüst's study mentioned above is concerned.

Figure 2, which is adapted from Coast and Geodetic Survey Chart 1007, visualizes the hydrographic features of the Gulf Stream for the first 400 miles of its course. The region where the Gulf of Mexico narrows to form the channel between Florida Keys and Cuba may be regarded as the head of the Gulf Stream. Here the width of its channel is 95 nautical miles. Eastward the channel becomes narrower, reaching its least width in the so-called narrows, abreast of Cape Florida, where it is but half its original width. From here it widens somewhat until it meets the open sea north of Little Bahama Bank.

---

[7] Otto Krümmel: Handbuch der Ozeanographie, 2 vols., Stuttgart, 1907–1911.

[8] Gerhard Schott: Geographie des Atlantischen Ozeans, 2nd edit., pp. 180–205, Hamburg, 1926.

[9] Georg Wüst: Florida und Antillenstrom, Veröffentl. Inst. für Meereskunde, No. 12, Berlin, 1924.

While the chart shows that in its first reach the Gulf Stream flows between banks like a river, it is to be noted that this channel is in two respects markedly different from that of a river. In a river, as a rule, the channel increases in width from head to mouth. But in the

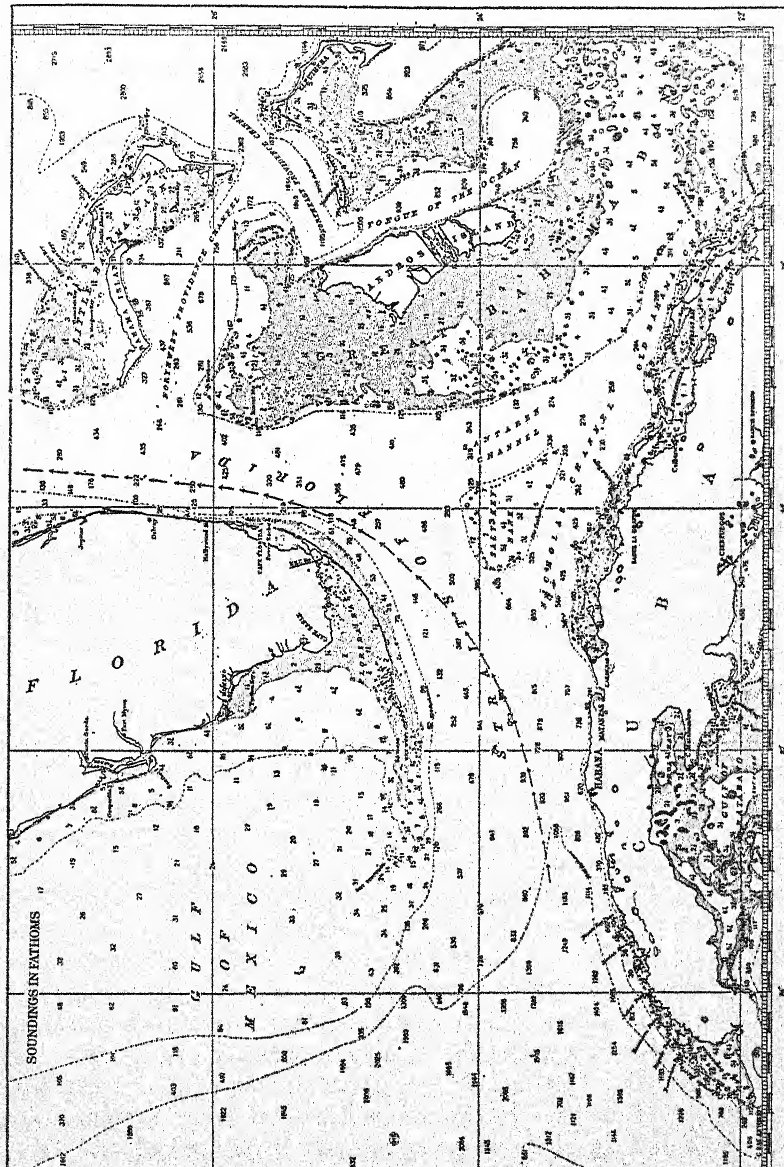


FIGURE 2.—Hydrographic features of the Gulf Stream within the Straits of Florida. (Adapted from U. S. Coast and Geodetic Survey Chart 1007)

Gulf Stream, as we have just seen, the width of the channel decreases seawards. Furthermore, a river deepens as it goes seaward; an examination of the chart, however, shows that the channel of the Gulf

Stream becomes shallower as it goes seaward. At its head, as shown in Figure 2, the stream shows depths of a thousand fathoms or more; but the depths gradually decrease, and when the channel approaches the sea the greatest depth is but little more than 400 fathoms.

Nautical charts are issued primarily for the mariner, to whom the shoal areas are critical. Hence in hydrographic surveys, as a rule, shoal areas are much more closely developed than areas of deep water. So that it may be assumed that the relief of the bottom of the Straits of Florida is indicated only in its larger features on the chart. It is quite likely that a detailed hydrographic survey of the straits would bring out interesting local features that now are masked.

Throughout the whole stretch of 400 miles shown in Figure 2, the Gulf Stream flows with considerable velocity. It is clear, however, that the whole mass of water is not moving with a uniform velocity. Confining our attention for the present to the velocity of the current at the surface we find at its head, say abreast of Habana, the velocity in the axis of the stream (shown by arrows in fig. 2) to be about 2½ nautical miles per hour, or 2½ knots on the average. Seaward, the velocity increases gradually as the cross-sectional area of the stream decreases until abreast of Cape Florida the velocity becomes about 3½ knots. As we shall see later, the current is subject to variations; and it is therefore to be emphasized that the velocities given above are approximate average or normal velocities.

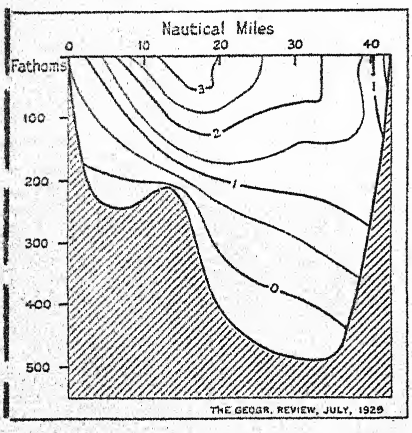


FIGURE 3.—Velocity of Gulf Stream within Straits of Florida

With regard to the current within the depths of the Gulf Stream the observational data are in general fragmentary. Pillsbury during his investigation carried out several series of current observations in the Straits of Florida, but these were generally confined to depths less than 1,000 feet. From these observations and from general considerations it is known that the swiftest thread of the current lies in the axis of the stream, just below the surface, and from ere the velocity decreases with increasing depth. In the axis of the Gulf Stream, off Habana, Pillsbury found the current setting easterly with a velocity of a knot at a depth of 130 fathoms.

Within the narrows of the strait, abreast of Cape Florida, the velocity distribution may be considered relatively well known. Figure 3, adapted from Wüst, shows the velocity distribution across the section

just south of Cape Florida. In constructing the velocity curves Wüst made use of Pillsbury's observations; and for the deeper parts, for which no observations are at hand, he derived the necessary data from a consideration of the temperature and salinity observations, which here extend from the surface to the bottom.

Within the Straits of Florida the Gulf Stream is generally pictured as a swiftly moving stream with but little variation in velocity from surface to bottom. Figure 3 shows, however, that only within a layer of about 200 fathoms (1,200 feet) does the velocity exceed 1 knot. Moreover, near the bottom, Pillsbury found the current setting southerly, that is, in a direction opposite to that of the main stream. This was taken to indicate a southerly flowing current, deriving perhaps from the Labrador Current. It appears, however, that it is more reasonably to be ascribed to eddies brought about by the upward-sloping bottom within the Straits of Florida.

With the details of the velocity distribution known, it becomes possible to compute the volume of water discharged by the Gulf Stream through the Straits of Florida. A rough estimate is easily made from Figure 3. In round numbers the channel eastward of Cape Florida has a width of 42 (geographical) miles and an average depth of 2,000 feet, or approximately one-third of a mile. This gives the area of the cross section here as 14 square miles. In round numbers, also, the velocity of the current through this section may be taken as 1 knot. Each hour, therefore, the Gulf Stream carries 14 cubic miles of water past this section into the sea. Since a geographical mile has a length of 6,080 feet and a cubic foot of sea water weighs approximately 64 pounds, we find that each hour the Gulf Stream carries 100 billion tons of water past Cape Florida into the sea.

The above calculation is clearly no more than a rough estimate; but it demonstrates that the hourly volume of the Gulf Stream is to be reckoned in scores of billions of tons. On the basis of his observations Pillsbury calculated the hourly volume of the Gulf Stream through the Straits of Florida as 90 billion tons. More recently Wüst, on the basis of data furnished by the observations and amplified by dynamical considerations, derived for this volume 89.96 cubic kilometers, or 14.1 cubic miles, which equals 101½ billion tons. In round numbers we may therefore take the average hourly volume of the Gulf Stream through the Straits of Florida to be 100 billion tons.

We may perhaps appreciate better the enormous volume of water that the Gulf Stream pours into the sea by comparing it with the volume discharged by the Mississippi River, which drains more than 40 per cent of the area of continental United States. On the average the Mississippi discharges about 664,000 cubic feet of water into the Gulf of Mexico each second. At extreme flood stage this volume becomes multiplied about threefold, mounting to about 1,800,000

82322—30——20

cubic feet per second.[10] On converting these figures into cubic (geographical) miles per hour they become, respectively, 0.01 and 0.03 cubic mile. The 14 cubic miles which the Gulf Stream hourly pours into the sea is thus more than 1,000 times the average discharge and very nearly 500 times the extreme flood discharge of the Mississippi.

THE WATER WITHIN THE STRAITS OF FLORIDA

With regard to the water poured so prodigally by the Gulf Stream into the sea through the Straits of Florida, the generally accepted notion is that it is of an unusually high temperature from top to bottom. Figure 4 shows the temperature of the water, in degrees Fahrenheit, across the section in the straits from Cape Florida eastward. This is adapted from Wüst, who made use of observations taken in May, 1878, and in March, 1914. Since, in general, the sea in the Northern Hemisphere is coldest in February and warmest in August, it may be taken that the temperatures shown in Figure 3 are approximately average temperatures.

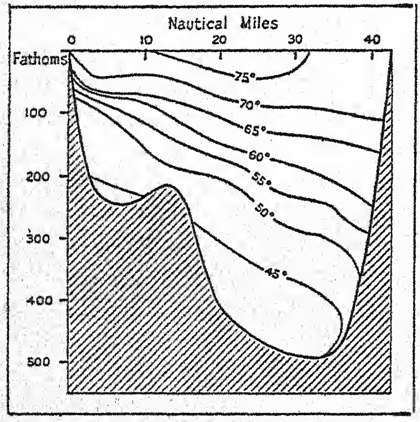


FIGURE 4.—Temperature of Gulf Stream waters within Straits of Florida

Obviously the Gulf Stream in the straits is not a homogeneous body of warm water. At the surface, in the center of the channel, the temperature is about 80°, and at the bottom it is 45° or even less. The fall in temperature is fairly rapid, a temperature of 50° being attained at about 200 fathoms, so that only a relatively shallow layer of the water is warm.

Figure 3 brings to light the fact that for any given depth the water on the eastern side of the channel is considerably warmer than that on the western. Thus at a depth of 100 fathoms the water on the Florida side of the straits has a temperature of about 50°, while on the Bahama side the temperature is about 70°. Furthermore, while the change in temperature with depth is approximately uniform on the Bahama side, it is decidedly not uniform on the Florida side, where a rapid change of 20° in temperature takes place between the depths of 50 and 100 fathoms. As regards temperature therefore, the water of the Gulf Stream is decidedly not homogeneous.

The prevailing conception of the Gulf Stream as an unusually warm body of water can be shown as erroneous from another point of view,

[10] J. L. Greenleaf: The Hydrology of the Mississippi, Amer. Journ. of Sci., Ser. 4. Vol. 2, pp. 29-46 1896; reference on p. 42.

namely, by comparison with other bodies of water in the same latitude, for example, with the Sargasso Sea. The surface waters of the Gulf Stream in the Straits of Florida have about the same temperature as the surface waters of the Sargasso Sea. But within the depths the Sargasso Sea is much warmer. At a depth of 200 fathoms the temperature of the latter is between 60° and 65°,[11] while in the Gulf Stream at that depth the temperature, as shown by Figure 4, averages about 55°.

With regard to other characteristics there is a like tendency to overrate the waters of the Gulf Stream. Highly saline these waters are, but not exceptionally so. On the customary salinity scale, in which each unit represents one part of salt in a thousand parts of water, the surface waters within the straits have a salinity of about 36. Below the surface the salinity increases gradually until a maximum of 36½ is reached at a depth of about 100 fathoms, after which the salinity decreases to about 35 at 300 fathoms, which salinity is then maintained to the bottom. In round numbers we may take the salinity of the waters within the straits as a whole to be 36. Compared to the average salinity of 34¾, which is accepted as the figure for the sea as a whole, the water within the straits is highly saline; but toward its eastern end the Sargasso Sea is more saline, having a salinity of 37½ on the surface and of about 36 at a depth of 300 fathoms. In depth of color and transparency, the waters in the Sargasso Sea likewise exceed those of the Gulf Stream.

In general, however, the Gulf Stream as it issues into the sea through the Straits of Florida may be characterized as a swift, highly saline current of blue water whose upper stratum is composed of warm water.

UNION WITH THE ANTILLES CURRENT

On issuing into the sea north of Little Bahama Bank the Gulf Stream loses the relatively great velocity which characterized it within the straits. From 3½ knots along the axis within the narrows of the straits, there is a gradual decrease to a velocity of about 2 knots off St. Augustine, Fla., in latitude 30° N. Here the Gulf Stream is joined by the Antilles Current, which flows northwesterly along the open ocean side of the West Indies before uniting with the Gulf Stream.

North of the thirtieth parallel of latitude, therefore, the Gulf Stream is a current to which two branches have contributed. It is no longer merely a continuation of the current that flows through the Straits of Florida. The latter current, for distinction, is frequently referred to as the Florida Current. As to the relative importance of the two branches of the Gulf Stream widely varying opinions have been

[11] Schott, op. cit., Pl. XIV, following p. 144.

entertained. Formerly it was thought that the Antilles Current furnished both the greater quantity of water as well as the greater quantity of heat transported by the Gulf Stream. Krümmel, for example, credits the Antilles Current with contributing about 2¾ times as much water and heat as the Florida Current. Wüst's study of the question, however, makes it appear that the rôles of the two currents must be reversed; for he finds on the basis of later data, that the Florida Current contributes about twice as much water and heat as the Antilles Current.

The Antilles Current, like the Florida Current, carries warm, highly saline water of clear indigo blue. The union of the two currents gives rise to a broad current possessing about the same characteristics as the Gulf Stream within the straits except that the velocity is much reduced. The combined current, under the influence of the deflecting force of the earth's rotation and the easterly trending coast line, turns more and more easterly, so that off the coast of Georgia the Gulf Stream bears northeast, maintaining this general direction past Cape Hatteras.

THE AXIS OF THE STREAM

From within the straits the axis of the Gulf Stream runs approximately parallel with the 100-fathom curve as far as Cape Hatteras, a distance of about 800 geographical miles. Since this stretch of coast line sweeps northward in a sharper curve than does the 100-fathom line, the axis lies at varying distances from the shore. Within the straits it is about 10 miles offshore; in the bight off the coast of Georgia this distance is about 100 miles; and at Cape Hatteras it is about 35 miles. In Figure 5 the axis is shown as compiled from Coast and Geodetic Survey Charts 1007 and 1001 and Hydrographic Office Chart 1411. On these charts the axis bears the following legends: "approximate axis of maximum strength" (Chart 1001); "approximate location of axis of Gulf Stream" (Chart 1007); "mean position of axis of Gulf Stream" (Chart 1411).

Even with a qualifying phrase directing attention to the fact that its location is only approximate, the axis of the Gulf Stream as it appears on a chart tends to convey a sense of definiteness and precision wholly at variance with the observed facts. The channel of the Gulf Stream is so wide and is characterized by so many irregularities that the simple flow postulated can be but the roughest approximation.

Strictly, we should distinguish between the temperature axis and the velocity axis of the Gulf Stream. The earlier systematic observations on the Gulf Stream dealt with the temperature of the water rather than with its motion. Hence the axis was taken to be the line along which the highest temperatures obtained. Later, the axis was taken to mark the line of greatest velocity. Ordinarily it is

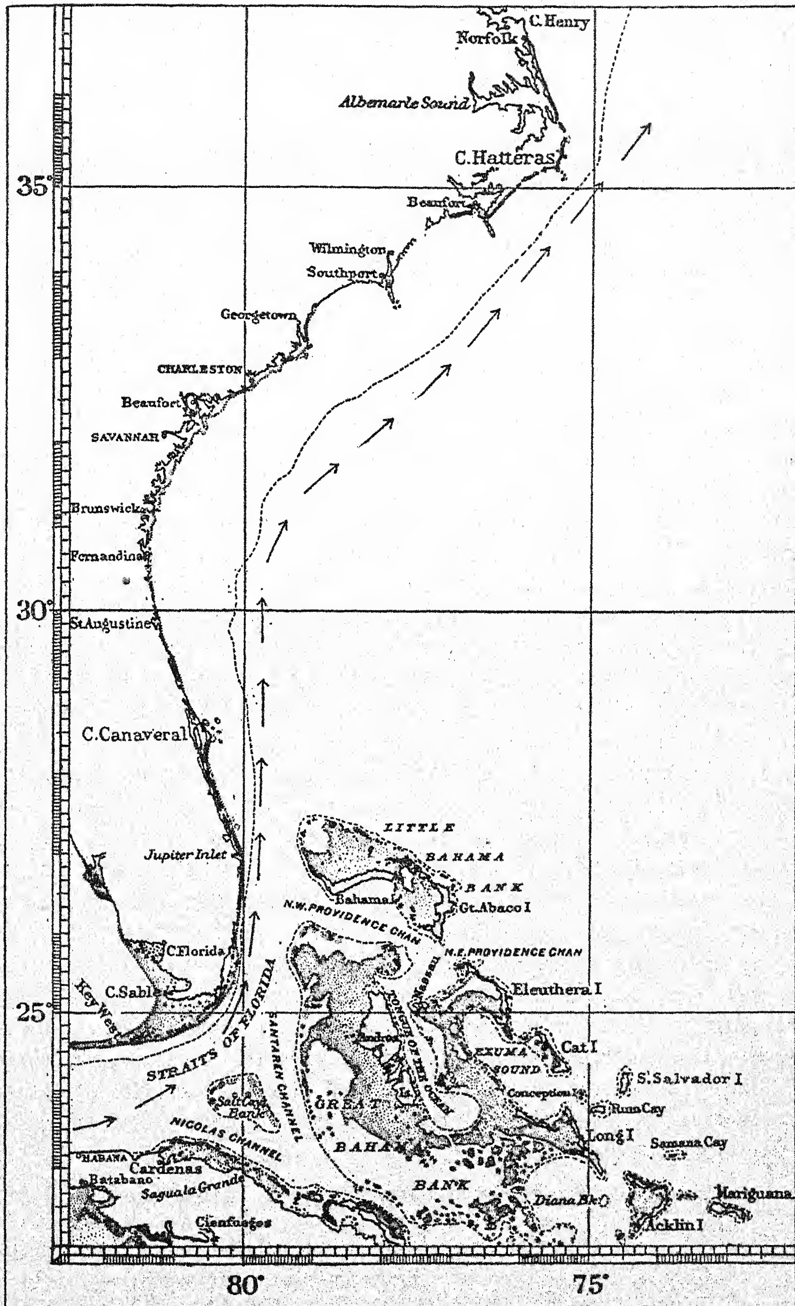


FIGURE 5.—The axis of the Gulf Stream. The dotted line represents the 100-fathom line

assumed that the two axes coincide; but this is by no means certain, and only systematic observations over a considerable period can solve this problem.

LATERAL BOUNDARIES

Within the straits the lateral boundaries of the Gulf Stream can be fixed with considerable precision. But when the stream issues into the sea, how are these boundaries to be determined? On the western side, to be sure, it is not difficult to define limits, since the waters of the stream differ in color, temperature, salinity, and flow from the inshore coastal waters. But on the east the Antilles Current comes to reinforce the Gulf Stream, so that its waters here merge gradually with the waters of the open Atlantic. In terms of color, temperature, and salinity it would be difficult to define the eastern limits of the Gulf Stream. With regard to direction of flow, however, we may fix the limits to include all the water flowing parallel to the axis. These limits vary with the seasons and with changing conditions of wind and weather. Furthermore, our knowledge of currents in the open sea is not yet sufficient to enable us to fix such limits with precision. Nevertheless, from such charts of the currents of the Atlantic as Schott's [12] and Meyer's [13] we may arrive at some approximately accurate estimate of the lateral extent of the Gulf Stream.

It has generally been taken that the inner edge of the Gulf Stream, from its outfall into the sea to Cape Hatteras, is defined by the 100-fathom curve. But recent observations by the Coast and Geodetic Survey indicate that it lies closer inshore. Systematic current observations made on board Diamond Shoals Light Vessel, which is anchored in 30 fathoms of water off the coast of North Carolina about 14 miles southeast of Cape Hatteras, give an average surface current here of 0.4 knot setting N. 58° E., which proves that along this stretch of the coast the inner edge of the Gulf Stream lies nearer the 20-fathom curve than the 100-fathom curve. Taking the inner limit of the Gulf Stream as far as Cape Hatteras to be defined by the 50-fathom curve, and the outer edge to be defined by a line along which the current is still approximately parallel to the axis of the Gulf Stream, the width of the stream northward of its outfall is as follows: Off Cape Canaveral, about 70 miles; off the coast of Georgia after its union with the Antilles Current, about 150 miles; off Cape Hatteras about 200 miles.

CONFLICT WITH THE LABRADOR CURRENT

The region off Cape Hatteras has been called the "delta" of the Gulf Stream, for here the widespreading current separates into a

---

[12] Schott, op. cit., Pl. XV, following p. 144.

[13] H. H. F. Meyer: Die Oberflächenströmungen des Atlantischen Ozeans im Februar, Veröffentl. Inst. für Meereskunde, No. 11, Berlin, 1923.

number of bands. This is most clearly evidenced by the juxtaposition of warm and cold bands of water of varying widths. This feature is also noted below Cape Hatteras but not in so marked a degree.

North of Cape Hatteras the Gulf Stream flows with a velocity averaging a little less than a knot, turning more and more eastward under the combined effects of the deflecting force of the earth's rotation and the eastwardly trending coast line, until the region of the Grand Bank of Newfoundland is reached. Here it comes into conflict with the southerly flowing Labrador Current which carries cold water of relatively low salinity.

THE COLD WALL

At an early stage of the investigations it was found that on its western or inner side the Gulf Stream was separated from the coastal waters by a zone of rapidly falling temperature, to which the term "cold wall" was applied. It is most clearly marked north of Cape Hatteras but extends, more or less well defined, from the straits to the Banks of Newfoundland. The abrupt change in the temperature of the waters separated by the cold wall is frequently very striking. Ward refers to an occasion in 1922 when the U. S. Coast Guard cutter *Tampa*, which is about 240 feet long, was placed directly across the cold wall, and the temperature of the sea at the bow was found to be 34° while at the stern it was 56°.[14]

In the vicinity of the Banks of Newfoundland the cold wall represents the dividing line between the warm waters of the Gulf Stream and the cold waters of the Labrador Current; and it seemed reasonable to invoke the cold waters of this current in explaining the existence of the cold wall and the relatively low temperatures of the coastal waters to the southward and westward. It was largely on this account that the waters of the Labrador Current were assumed to flow all along the eastern coast of the United States.

Recent observations, however, do not bear out this explanation. Current observation on various light vessels along the Atlantic coast of the United States made in recent years by the Coast and Geodetic Survey give no evidence of a predominant southerly movement of the water along the coast. From the observations made by the International Ice Patrol, Smith concludes that there is no southwest flow of the Labrador Current across the Great Bank, but that it "turns sharply, between parallels 42 and 43 and meridians 51 and 52, to flow easterly, parallel with the Gulf Stream."[15] In his study of the Gulf of Maine, Bigelow gave careful consideration to this question. His

---

[14] R. DeC. Ward: A Cruise with the International Ice Patrol, Geogr. Rev., vol. 14, pp. 50–61; 1924. reference on p. 54.

[15] Edward H. Smith: Oceanographic Summary, in "International Ice Observation and Ice Patrol Service in the North Atlantic Ocean, Season of 1922," U. S. Coast Guard Bull. No. 10, pp. 93–97; Washington, 1923, reference on p. 97.

conclusion is that he has "no hesitation, therefore, in definitely asssert-ing that the Labrador Current does not reach, much less skirt, the coast of North America, from Nova Scotia southward, as a regular event."[16]

Several agencies appear to be responsible for the cooler coastal waters along the eastern coast of the United States. In the first place into this area the rivers bring their drainage waters from the land, these waters being for the greater part of the year much colder than the open ocean waters. Another contributory cause is the deflection by the earth's rotation of cold water from the Gulf of St. Lawrence against the American coast. Then, too, the coastal waters are closer

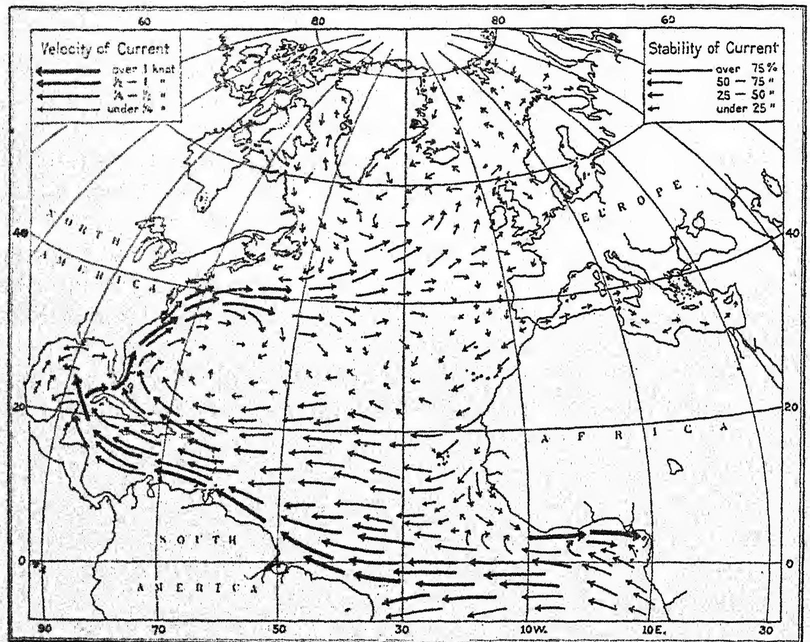


FIGURE 6.—Surface currents of the North Atlantic Ocean

to the low winter temperatures of the land and are thus made colder than the open ocean waters. A further cause is found in the winds, which along the coast of the United States are prevailingly from the land. This tends to drive the warmer surface water seaward, its place being taken by the cooler subsurface waters.

THE NORTH ATLANTIC DRIFT

When we come to a study of the horizontal circulation of the North Atlantic Ocean we find a complex system of interrelated currents, as is evident from a glance at Figure 6. In this figure, which is adapted

[16] H. B. Bigelow: Physical Oceanography of the Gulf of Maine, U. S. Bur. of Fisheries, Doc. No. 969, p. 828, Washington, 1927. See also H. B. Bigelow: Exploration of the waters of the Gulf of Maine, Geogr. Rev., Vol. 18, pp. 232-260, 1928.

from Schott, three characteristics of the currents are indicated. The direction of the current at any point is shown by the direction of the arrow at that point; the strength of the current or its velocity is indicated by the width of the arrow; and the stability of the current is indicated by the length of the arrow. The stability of the current at any point is expressed as a percentage and is a measure of the constancy of direction of the current at that point. The derivation of the numerical value of the stability involves technical details [17] which need not detain us here.

In a very real sense the circulation indicated by Figure 5 constitutes a single-current system; for a movement of the water at any point implies corresponding movements and return currents at other points, all these movements together forming a system of circulation. However, the large area covered by the North Atlantic Ocean and more particularly the different characteristics of the moving masses of water as regards temperature, salinity, and velocity make it convenient to designate various parts of the system by distinctive names, as for example the North Equatorial Current or Canary Current.

Starting at any given point various circuits may be traced on a current chart. The one which, under the name of Gulf Stream, we have followed from the Straits of Florida as far as the Banks of Newfoundland may be traced further eastward and northeastward to the coastal waters of northwestern Europe, as shown in Figure 6. Shall this current circuit from the eastern coast of the United States to northwestern Europe be designated by the single name Gulf Stream? Or shall we limit the name Gulf Stream to the stretch from the Straits to the Banks of Newfoundland, since in this stretch the characteristics of the current are much the same? If it is the northeasterly transport of warm water across the Atlantic that one has in mind, a single name like Gulf Stream or North Atlantic Current has many advantages. If, however, the causes and details of the movement of the water are being studied, the phenomena are more clearly apprehended by giving the current eastward of the Banks of Newfoundland some such name as Gulf Stream Drift or North Atlantic Drift. It is a slow current, the velocity averaging less than half a knot, and its movement is due in large part to the westerly winds which prevail over this stretch of the ocean.

The validity of the conception underlying the representation of the movement of the waters in the Gulf Stream and in the North Atlantic Drift by current charts like Figure 7 has been assailed in recent years by Dr. E. Le Danois. In a paper published in 1924 [18] he elaborates the thesis that the movement of the waters of the

---

[17] Krümmel, *op. cit.*, Vol. 2, p. 441.

[18] E. Le Danois: Étude hydrologique de l'Atlantique-Nord, Annales Inst. Oceanographique, Vol. 1 (N. S.), pp. 1-52 ,1924.

North Atlantic consists of two currents—a circumpolar current and an equatorial current—and various so-called transgressions, by which name he denominates slow periodic movements of the water of the nature of long-period tidal movements. The Gulf Stream in particular he reduces to a mixture of the equatorial current with the tidal current from the Gulf of Mexico, which tidal current he mentions as being violent. "This tidal current—the true Gulf Stream—is compelled to move into the open sea by the presence of the last waters of the Labrador Current which skirt the coast of the United States" (p. 19).

Now there are data at hand, as we shall see later, which completely disprove the existence of violent tidal currents in the Gulf of Mexico.

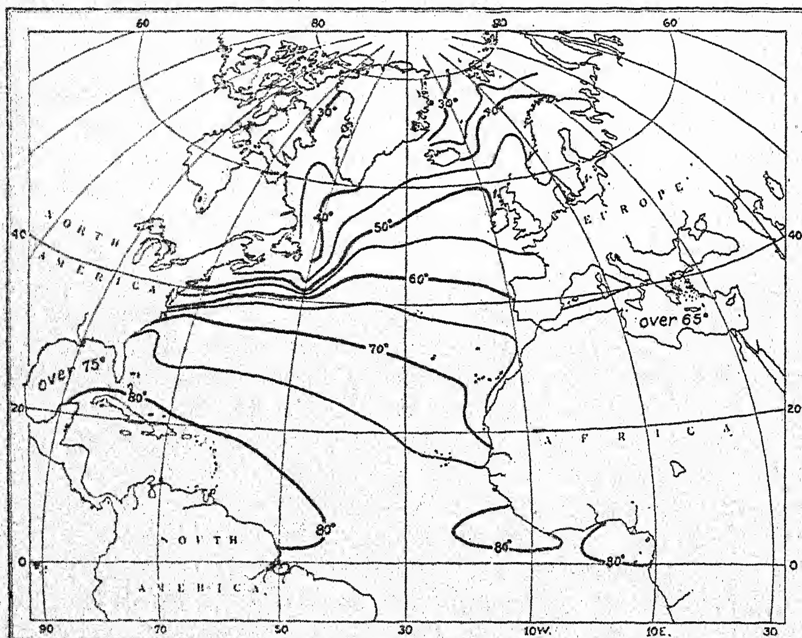


FIGURE 7.—Isotherms of the surface waters, North Atlantic Ocean. (Adapted from Schott)

Moreover, in characterizing the current in the Straits of Florida as a tidal current Le Danois must have in mind something quite different from what is commonly understood by the term, namely, a periodic forward and backward movement of the water with a period of half a day or a day. And in invoking the presence of the Labrador Current along the coast of the United States he surely does not strengthen his case; for, as we have seen, the view that the Labrador Current reaches the coast of the United States is no longer tenable.

The reality of the movement of the water from the lower latitudes of the western North Atlantic to the higher latitudes of the eastern

North Atlantic is not only evidenced by a chart of the currents but is also clearly indicated by the temperature of the surface waters. In Figure 7 the isotherms of the surface waters of the North Atlantic are shown for each five degrees Fahrenheit. The northerly sweep of the isotherms in the eastern North Atlantic points clearly to the existence of a current moving easterly and northerly across this oceanic basin.

CAUSES OF THE GULF STREAM

Ocean currents may arise from any one or more of a number of causes. Some of these causes reside within the sea itself, others originate without. Differences in level between two regions of an ocean basin, brought about by whatever agencies, will result in a surface current from the higher to the lower level. Differences in density, whether arising from difference in temperature or in salinity or both, will bring about a subsurface current from and a return surface current to the region of greater density. Differences in atmospheric pressure between two regions will, in the same way, bring in their train a subsurface current from and a return surface current to the region of greater pressure. And in the wind we have at once the most obvious and the most familiar of the agencies that bring about ocean currents.

In a current traversing so long a course as that of the Gulf Stream it is plain that all the agencies enumerated above enter as factors. Clearly, too, the relative importance of the different agencies must vary in different parts of the course. But various problems of an hydrodynamic character must yet be solved before a numerical evaluation of the relative importance of the agencies concerned in the movement of the Gulf Stream is possible.

A century and a half ago Franklin thought that the Gulf Stream "is probably generated by the great accumulation of water on the eastern coast of America between the tropics, by the trade winds which constantly blow there." And in the trade winds, which bring about a westerly flow of the waters in the equatorial regions of the Atlantic Ocean, is still found the primary cause of the Gulf Stream. As appears from Figure 6, the waters of the South Equatorial Current are the first to strike the coast, the greater part being directed northwestward into the Caribbean Sea where they reinforce the flow of the North Equatorial Current. From the Caribbean the combined flow comes into the Gulf of Mexico whence it issues as the Gulf Stream into the Straits of Florida.

Now while the Gulf Stream is traced to the trade winds, the stream is not a wind or drift current as are the North and South Equatorial Currents. The accumulation of water resulting from the trade winds brings about a gradient current. This means that a higher level of

the water must obtain in the Gulf of Mexico than out in the open sea north of the Straits of Florida. Agassiz quotes Hilgard as regarding the Gulf of Mexico "as an immense hydrostatic reservoir rising to the height of more than 3 feet above the general oceanic level, and from this supply comes the Gulf Stream, which passes out through the Straits * * * the only opening left for its exit." [19] And in a footnote he adds, "By a most careful series of levels, run from Sandy Hook and the mouth of the Mississippi River to St. Louis, it was discovered that the Atlantic Ocean at the first point is 40 inches lower than the Gulf of Mexico at the mouth of the Mississippi." In a paper published in 1914 Hepworth states, "As regards the Gulf Stream, and its causation, it was found by the officers of the United States Coast Survey that the Atlantic Ocean at Sandy Hook was 3 to 4 feet lower than the waters of the Gulf of Mexico at the mouth of the Mississippi." [20]

It should be remembered that leveling of even the highest precision is subject to instrumental errors which, while very small for moderate distances, may become relatively large between widely separated points. More recent results reduce very much the difference in level between the Gulf of Mexico and the Atlantic and bring to light the fact that this is a highly involved matter. Avers recently studied this question in connection with the broader question of the deviations of local sea level from a level surface.[21] His results, which are based on the best available data, may be summarized as follows: From Galveston, Texas, to Cedar Keys, on the west coast of Florida, the level of the Gulf slopes downward, the difference between the two places being 0.43 foot. The level of the Gulf at Cedar Keys is 0.36 foot higher than the level of the Atlantic Ocean at St. Augustine on the eastern coast of Florida. But from St. Augustine northward there is an upward slope of sea level all along the Atlantic coast of the United States; so that in the vicinity of Sandy Hook sea level is actually 0.62 foot higher than at St. Augustine and but 0.16 foot below the Gulf level at Galveston.

This upward slope of sea level along the Atlantic coast of the United States does not necessarily mean that the Gulf Stream is moving uphill. For the main body of the Gulf Stream is a number of miles off the coast, and there may well be a downward slope of sea level outward from the coast. The question of sea level itself is one complicated by many factors, and the exact determination of the difference in level between the Gulf and the open sea bristles with numerous unsolved problems.

---

[19] Alexander Agassiz: Three Cruises of the United States Coast and Geodetic Survey Steamer "Blake" Vol. 1, p. 249, Boston and New York, 1888.

[20] M. W. Campbell Hepworth: The Gulf Stream, Geogr. Journ., Vol. 44, pp. 429–452 and 534–553, 1914; reference on p. 435.

[21] H. G. Avers: A study of the Variation of Mean Sea-Level from a Level Surface, Bull. Natl. Research Council, No. 61 (=Trans. Amer. Geophys. Union, 1927), pp. 56–58, Washington, 1927.

FLUCTUATIONS OF THE GULF STREAM

The Gulf Stream manifestly must be subject to fluctuations as regards location, velocity, and temperature. Heavy winds will not only carry its waters into regions which at other times it does not invade but will also accelerate or retard its velocity. Variations in barometric pressure likewise will bring about fluctuations in the movement of the waters of the stream. Seasonal variations in temperature in the regions through which it flows will be reflected in somewhat similar seasonal variations in the temperature of its waters. A further cause for its fluctuation is found in the fluctuations of the currents which feed it or which, like the Labrador Current, come into conflict with it.

Fluctuations in the velocity of the Gulf Stream are noted by Pillsbury. He refers to an occasion, while he was at anchor in the Straits of Florida, when the velocity of the current at the surface increased from 3.3 knots to 4.6 knots in less than an hour. He speaks, too, of "a regular daily variation in velocity which amounts in some instances to nearly 2½ knots" (p. 546). This regular daily variation he regarded as of the nature of a tidal effect. His observations were later subjected to harmonic analysis by Harris, who found the principal constituent of the tidal current to have a velocity of less than a quarter of a knot.[22] The tidal current in the Straits of Florida is therefore of negligible velocity, and the fluctuations noted by Pillsbury are undoubtedly irregularities which accompany the flow of water in large masses.

Pillsbury was also of the opinion that, in addition to this so-called regular daily variation and to fluctuations arising from changes in wind and weather, the Gulf Stream within the Straits of Florida was subject to periodic monthly variations in both temperature and velocity which depend on the declination of the moon. The observations are not, however, sufficiently extensive to settle this question definitely. The reality of such variations is still in question, and it would not be at all surprising if further investigation should disprove any such relationship.

In a paper before the American Meteorological Society on Temperature Variations in the Gulf Stream in the Straits of Florida, 1917–1921,[23] Hazel V. Miller presented the results of a study of several thousand readings of surface-water temperature made by observers on the Key West-Habana car ferries across the Straits of Florida for the 4-year period 1917–1921. The temperature was found to range from a minimum of about 76° in January to about 86°

[22] R. A. Harris: Manual of Tides, Part V: Currents, Shallow-Water Tides, Meteorological Tides, and Miscellaneous Matters, U. S. Coast and Geodetic Survey Rep. for the Year Ending June 30, 1907, Appendix 6, pp. 231–545 Washington, 1907; reference on pp. 411–412.

[23] Abstract in Bull. Amer. Meteorol. Soc., Vol. 7, pp. 87–88, 1926.

in September, while variations of as much as 4° from week to week under the influence of a strong wind were noted. A comparison of weekly temperatures with winds brought out clearly immediate and persisting effects of the wind as regards both direction and velocity.

From the nature of the agencies concerned, fluctuations from day to day in the flow and temperature of the Gulf Stream may be taken for granted. Seasonal variations likewise are unquestionable, as are smaller fluctuations from year to year. Vilhelm Pettersson studied the temperature data derived from ships' logs, covering the Gulf Stream up to latitude 33° N., for the 14-year period 1900–1913. He found that the temperature of the surface waters varies from year to year, generally by less than 1° but sometimes by more than a degree.[24] Whether these yearly variations are, in large or small part, of a periodic nature is at the present time, for lack of sufficient data, an open question.

The difficulties involved in securing systematic observations on the temperature and flow of the Gulf Stream to determine the nature and extent of its fluctuations are obvious. The observations recorded in navigators' log books furnish valuable information, but such observations are not sufficient of themselves. More hopeful is the slowly growing use of sea-water thermographs aboard ships. From the records furnished by these instruments definite information regarding fluctuations in the temperature of the Gulf Stream waters should result.

In the light of the preceding considerations the question of whether there has been any permanent change in the course or in the temperature of the Gulf Stream since it has been known to civilized man, may be answered shortly. Manifestly, without extensive observations which would permit comparisons, no categorical answer can be given. But it is clear that any decided change in an ocean current of the magnitude of the Gulf Stream can come only as the result of extensive changes in such features as the bottom of the ocean, the configuration of the coast line, or the prevailing winds. Since no such extensive changes appear to have taken place, it is highly improbable that any decided change in the course of the Gulf Stream has occurred since it has become known.

CLIMATIC EFFECTS

A host of problems lie covered by the question of the climatic effects of the Gulf Stream. That its warm waters have an ameliorating effect on the lands near which they flow is a strongly held opinion;

---

[24] V. I. Pettersson: Étude de la statistique hydrographique du Bulletin Atlantique du Conseil International pour l'Exploration de la Mer, Svenska Hydrogr.-Biol. Komm. Skrifter, Hydrografi I (N. S.), p. 4, 1926.

and now and again schemes are seriously proposed to change the course of the Stream with a view to moderating the winter climate of our Northeastern States.

A moment's consideration is sufficient to show that the direct influence of the Gulf Stream on the climate of the greater part of the eastern coast of the United States is altogether negligible. For, aside from latitude, our climate depends mostly on the direction from which the winds come and the force with which they blow. In winter the winds along the northeastern coast of the United States are prevailingly from the northwest, that is from the land. Hence the warm waters of the Gulf Stream lying several hundred miles to the leeward can in no way moderate our winter climate.

These considerations are sufficient also to prove the absurdity of the proposals for changing the course of the Gulf Stream in the interests of a more equable climate. Furthermore, the forces that give rise to the Gulf Stream are of such magnitude that they are not yet amenable to control by man. But even if the Gulf Stream could be brought nearer our shores, the climate could be moderated only if the winter winds could be made to blow from the south or the southeast.

Indeed, there are good reasons for believing that if the Gulf Stream were to shift closer to the coast the climate of our Northeastern States would become more extreme rather than moderated—colder and more stormy in winter, hotter and more humid in summer. For, with warm air near the coast in winter, a greater flow of air from the northwest would result, bringing severer storms and colder weather. In summer, the winds along the coast are more or less sea breezes, bringing the cooler air from the sea to moderate the heat. With warmer air nearer shore, the sea breezes would become weaker and less frequent, thus giving wider scope for the hot land winds.

While the moderating effect of the Gulf Stream on the climate of North America is negligible, there is no question as to its beneficent effects on the climate of northwestern Europe. Scandinavia and southeastern Greenland face each other across the intervening waters of the Atlantic Ocean along the same parallels of latitude. Contrast the populous and prosperous lands of the one with the bleak and inhospitable shores of the other!

It is to be observed that the tempering influence of the Gulf Stream on the climate of northwestern Europe is effected through the agency of winds. In winter the winds are there prevailingly from the southwest. Blowing over the relatively warm water which the Gulf Stream (using the term as embracing also the North Atlantic Drift) has brought to the northeastern rim of the Atlantic, they carry warm air onto the coast. It is through this mechanism that the heat exchange

in winter between the Gulf Stream and the air of northwestern Europe takes place.

How great the influence of the Gulf Stream on the climate of northwestern Europe is, becomes evident from the fact that the average temperature for the month of January in northern Norway is about 45° above the January temperature normal for that latitude.[25] Hammerfest, on the north coast of Norway in latitude 70° 40′ N.—well within the Arctic Circle—is an important harbor and sea-fishing center during the winter, while the port of Riga, about 800 miles farther south is obstructed by ice throughout the season.

Since the climate of northwestern Europe is so strongly influenced by the Gulf Stream, should not fluctuations in the latter find reflection in changes in the climatic conditions of this region? At first glance the differences in temperature of the Gulf Stream from year to year—something like 1°—might appear insignificant in such a connection. But the fact is not to be overlooked that the capacity of water for heat is so great that when a given volume of water gives off the heat represented by a fall of 1° in temperature, a mass of air more than 3,000 times that volume will have its temperature raised 1°.

A direct attack on this problem is difficult because of the lack of systematic observations on the temperature and flow of the Gulf Stream. Otto Pettersson studied the temperature variations of the water at several places along the Norwegian coast and found that these variations were reflected by corresponding variations in various climatic phenomena.[26] The problem clearly is a complicated one involving the question of the mutual interaction of ocean and atmosphere. A considerable literature has grown up around this, which is summarized by Helland-Hansen and Nansen.[27]

One phase of this problem links with the question of long-range weather forecasts. It is a long circuit that is traversed by the Gulf Stream from its place of orgin in the subtropical regions to the coasts of northwestern Europe. How long a period intervenes between fluctuations in the stream and the resultant climatic effects in Europe? This problem, too, can not yet be attacked directly, because of the lack of systematic observations. Such investigations as have been made show this to be a promising field. Thus Otto Pettersson found that the date when spring plowing could commence near Upsala depended on the temperature of the water of the Atlantic off the coast of Norway about two months previous. Vilhelm Pettersson found that the sum-

---

[25] J. W. Sandström: Über den Einfluss des Golfstromes auf die Winter-temperatur in Europe Meteorol. Zeitschr., Vol. 43, pp. 401–411 1926; reference on p. 401.

[26] Otto Pettersson: Über die Beziehungen zwischen hydrographischen und metorologischen Phänomenen, Meteorol. Zeitschr., Vol. 13, pp. 285–318, 1896.

[27] Björn Helland-Hansen and Fridtjof Nansen: Temperature Variations in the North Atlantic Ocean and in the Atmosphere, Smithsonian Misc. Coll., Vol. 70, No. 4, pp. 26–51, Washington, 1920.

mer temperature of the water in the region between Newfoundland and Ireland gave an indication of the rainfall in Ireland and Great Britain in the following year.

Obviously the problem of unraveling the relationship between changes in the Gulf Stream and weather conditions several months hence is not a simple one. Climatic conditions in any given region of the North Atlantic result from the interplay of a number of factors. Similarly, the temperature of the stream at any given time is brought about by the interaction of a number of agencies. Nevertheless it appears that in the study of the fluctuations of the Gulf Stream lies the possiblilty of long-range weather forecasts for a considerable part of Europe.

82322—30——21

THE MYSTERY OF LIFE[1]

By F. G. Donnan, F. R. S.

During the last 40 years the sciences of physics and chemistry have made tremendous strides. The physicochemical world has been analyzed into three components—electrons, protons, and the electromagnetic field with its streams of radiant energy. Concurrently with these advances astronomy has progressed to an extent undreamed of 40 years ago. The distances, sizes, masses, temperatures, and even the constitutions of far-distant stars have been ascertained and compared. The evolution of the almost inconceivably distant nebulæ and their condensation into stars and star clusters have been unraveled with a skill and knowledge that would have been deemed superhuman a hundred years ago. Amidst the vast cosmos thus disclosed to the mind of man, our sun winds its modest way, an unimportant star, old in years and approaching death. Once upon a time, so the astronomers tell us, its surface was rippled by the gravitational pull of a passing star, and the ripples becoming waves, broke and splashed off. Some drops of this glowing spray, held by the sun's attraction in revolving orbits, cooled down and became the planets of our solar system. Our own planet, the earth, gradually acquired a solid crust. Then the water vapor in its atmosphere began to condense, and produced oceans, lakes and rivers as the temperature sank. It is probably at least a thousand million years since the earth acquired a solid crust of rock. During that period living beings, plants and animals, have appeared, and, as the story of the rocks tells us, have developed by degrees from small and lowly ancestors. The last product of this development is the mind of man. What a strange story! On the cool surface of this little planet, warmed by the rays of a declining star, stands the small company of life. One with the green meadows and the flowers, the birds and the fishes and the beasts, man with all his kith and kin counts for but an infinitesimal fraction of the surface of the earth, and yet it is the mind of man that has penetrated the cosmos and discovered the distant stars and nebulæ. Truly we may say that life

[1] Evening discourse before the British Association for the Advancement of Science at the Glasgow Meeting, 1928. Reprinted by permission of the association.

is the great mystery and the study of life the greatest study of all. The understanding of the phenomena of life will surely be the crowning glory of science, toward which all our present chemical and physical knowledge forms but the preliminary steps.

Observing the apparent freedom, spontaneity and, indeed, waywardness of many forms of life, we are at first lost in amazement. Is this thing we call life some strange and magical intruder, some source of lawless and spontaneous action, some fallen angel from an unknown and inconceivable universe? That is indeed the question we have to examine, and we may begin our examination in a general way by inquiring whether living things are subject to the laws of energy that control the mass phenomena of the inanimate world. The first of these laws, known as the law of the conservation of energy, says that work or energy can only be produced at the expense of some other form, and that there are definite rates of equivalence or exchange between the appearing and disappearing forms of energy. In a closed system we can make up a balance sheet, and we find that the algebraic sum of the increases and decreases, allowing, of course, for the fixed rates of exchange, is zero. That was one of the great discoveries of the nineteenth century. The physiologists have found that living beings form no exception to this law. If we put a guinea pig or a man into a nutrition calorimeter, measure the work and heat produced and the energy values of the food taken in and the materials given out, we find our balance sheet correct. The living being neither destroys nor creates energy. One part of the apparent freedom or spontaneity of which I spoke is gone. Energy-producing action must be paid for by energy consumed. The living being does not break the rules of exchange that govern the markets of the nonliving and the dead.

Another great discovery of the nineteenth century, the so-called second law of thermodynamics, restricts the direction of energy transformations. Thus a large tank of hot water at an even temperature will not be found to cool itself and the disappearing heat energy to appear as the kinetic energy of a revolving flywheel or as the increased potential energy of a raised mass of metal, no other changes of any sort having taken place. Such a transformation need not, however, in any way conflict with the law of conservation. Uncoordinated energy in statistical equilibrium, i. e., of even potential, does not spontaneously transform itself into coordinated energy. Now it would be a discovery of tremendous importance if plants or animals were found to be exceptions to this rule. But, so far as is known, the facts of biology and physiology seem to show that living beings, just like inanimate things, conform to the second law. They do not live and act in an environment which is in perfect physical and chemical equilibrium. It is the nonequilibrium, the free or available energy of the environment which is the sole source of their life and

activity. A steam engine moves and does work because the coal and oxygen are not in equilibrium, just as an animal lives and acts because its food and oxygen are not in equilibrium. As Bayliss has so finely put it, equilibrium is death. The chief source of life and activity on this planet arises from the fact that the cool surface of the earth is constantly bathed in a flood of high-temperature light. If radiation in thermal equilibrium with the average temperature of the earth's crust were the only radiant energy present, practically all life as we know it would cease, for then the chlorophyll of the green plants would cease to assimilate carbonic acid and convert it into sugar and starch. The photochemical assimilation of the green plant is a fact of supreme importance in the economy of life. This transformation of carbonic acid and water into starch and oxygen represents an increase of free energy, since the starch and oxygen tend naturally to react together and give carbonic acid and water. Such an increase in free energy would be impossible if there existed no compensating running down or degradation of energy. But this running down or fall in potential is provided by the difference in temperature between the surface of the sun and the surface of the earth, a difference of some five or six thousand degrees. All living things live and act by utilizing some form of nonequilibrium or free energy in their environment. The living cell acts as an energy transformer, running some of the free energy of its environment down to a lower level of potential and simultaneously building some up to a higher level of potential. The nitrifying bacteria investigated by Winogradsky and recently by Meyerhof utilize the free energy of ammonia plus oxygen. By burning the ammonia to nitrous or nitric acid they are enabled to assimilate carbonic acid and convert it into sugar or protein. Other bacteria utilize the free energy of sulphuretted hydrogen plus oxygen. Fungi and anærobic bacteria utilize the free energy available when complex organic compounds pass into simpler chemical compounds. The close study of these energy exchanges and transformations is becoming a very important branch of cellular physiology, and in the hands of Warburg and Meyerhof in Germany and of A. V. Hill in England—to mention only a few eminent names—has already yielded results of the greatest value and importance. It would be a great thing if one of these investigators were to find a case where the second law of thermodynamics broke down. Up to the present, however, it appears that all these energy transformations of the living cell conform with the second law as it applies to the inanimate world. Thus another part of the apparent freedom or spontaneity of life, of which I spoke before, disappears. A living being is not a magical source of free energy or spontaneous action. Its life and activity are ruled and controlled by the amount and nature of the free energy, the physical or chemical nonequilibrium, in its immediate environment, and it

lives and acts by virtue of this. The cells of a human brain continue to act because the blood stream brings to them chemical free energy in the form of sugar and oxygen. Stop the stream for a second and consciousness vanishes. Without that sugar and oxygen there could be no thought, no sweet sonnets of a Shakespeare, no joy, and no sorrow.

To say, however, that the tide of life ebbs and flows within the limits fixed by the laws of energy, and that living beings are in this respect no higher and no lower than the dead things around us is not to resolve the mystery. Consider for a moment a few of the phenomena exhibited by living things. The fertilization of the ovum, the growth of the embryo, the growth of the complete individual, the harmonious organization of the individual, the phenomena of inheritance, of memory, of adaptation, of evolution. Viewing these phenomena in the light of the facts known to physics and chemistry, it is little wonder that some modern philosophers have followed in the steps of certain older ones and seen in the phenomena of life the operation of some strange and unknown vital force, some "entelechy," some expanding vital impulse; or at least some new and undiscovered form of "biotic" or "nervous" energy. It is difficult to resist the comparison of the developing embryo with the building of a house to the plans of an invisible architect. Growth and development seem to proceed on a definite plan and apparently purposeful adaptation confronts us at many stages of life. How can the differential equations of physics or the laws of physical chemistry attempt to explain or describe such strange and apparently marvelous phenomena? The answer to this question was given more than 50 years ago by the great French physiologist, Claude Bernard. We must patiently proceed, he said, by the method of general physiology. This is the fundamental biological science toward which all others converge. Its method consists in determining the elementary condition of the phenomena of life. We must decompose or analyze the great mass phenomena of life into their elementary unit or constituent phenomena. That was the great answer given by Claude Bernard. It is worthy of a Newton or an Einstein. It sounded the clarion note of a new era of biological science. To-day general physiology in its application of physics, chemistry, and physical chemistry to the operations of the living cell is the fundamental science of life. Patiently pursued, and step by step, it is unraveling the mystery. The late Professor Bayliss was one of the greatest of the pioneer successors of Claude Bernard in England. Another of the greatest ones was Jacques Loeb in America, whose death we all so deeply deplore. Although it is always invidious to mention the names of living men, it is good to think that in England to-day we possess three of the greatest living exponents of general physiology, namely, Barcroft, Hill, and Hopkins, while in America the great work of Jacques Loeb is

carried on by distinguished men of the high caliber of Lawrence Henderson, Osterhout, and van Slyke. In Germany we have such great names as Meyerhof, Warburg, Bechhold, and Höber, to mention only a few. What are these men attempting? Just what Claude Bernard set out in his program, namely, by a patient, exact, and quantitative application of the facts and laws of physics and chemistry to the elementary phenomena of life, gradually to arrive at a synthesis and understanding of the whole. That was precisely how Newton was able to determine the motions of celestial objects, namely, by going back to the elementary or fundamental law of gravitation. Through fine analysis to synthesis is indeed the only true scientific method. I do not mean that general physiology in the pursuit of its studies will not discover many things as yet unknown to us. The future findings of this science might be as strange to the investigators of to-day as the relativity theory of Einstein and Minkowsky was to the physicists of a few years ago. What I do mean is that the future discoveries and explanations of general physiology will be continuous and homologous with the science of to-day. Should, indeed, a new form of energy, "a vitalistic nervous energy," be discovered, as predicted by the eminent Italian philosopher, Eugenio Rignano, it will be no twilight will-o'-the-wisp, no elusive entelechy or shadowy vital impulse, but an addition to our knowledge of a character permitting of exact measurement and of exact expression by means of mathematical equations.

To give you the barest outline of the progress made by general physiology since the death of Claude Bernard 50 years ago (his statue, together with that of Marcellin Berthelot, stands in front of the Collège de France) would require at least a hundred lectures and the encyclopædic knowledge of a Bayliss. Permit me, however, to mention one or two examples, and those with all brevity. The chemistry and energy changes of muscle have been discovered recently by Meyerhof in Germany and by A. V. Hill and Hopkins in England. When the muscle tissue contracts and does work it derives the necessary free energy, not from oxidation, which is not quick enough, but from the rapid exothermic conversion of the carbohydrate glycogen into lactic acid. When the fatigued muscle recovers it recharges its store of free energy; that is to say, by oxidizing or burning some of the carbohydrate, it reconverts the lactic acid into glycogen. Thus in the recovery stage we have the coupled reactions of exothermic oxidation and endothermic conversion of lactic acid into glycogen. Everything proceeds according to the laws of physics and chemistry. The story of the mode of action and recovery of the muscle cells forms one of the most fascinating chapters of general physiology. Here we see one of the elementary phenomena of life already to a great extent analyzed and elucidated. How this would have rejoiced the heart of Claude Bernard! That is one of the examples which I wished to

mention. Another is what I may call the blood equilibrium. The red blood cells are inclosed in a membrane which does not allow the hæmoglobin to escape, and only permits the passage of inorganic anions, though water and oxygen can pass freely in and out. Between the red cells and the external blood plasma in which they are submerged there exists a whole series of delicate exchange equilibria, such as water or osmotic equilibrium, ion-distribution equilibria, etc. The entrance of oxygen, which combines with the hæmoglobin, converts it into a stronger acid and ejects carbonic acid from the bicarbonate ions within the cell. Any disturbance of one of these equilibria produces compensating changes in the others. The whole series of equilibria can be written down in a set of precise mathematical equations. Thus two of the most important elementary phenomena of many forms of life, namely, respiration and the exchanges of the red blood cells, have been analyzed, subjected to exact measurement and described by exact mathematical equations. The laws of physics and chemistry have again been found to hold good. The beautiful story of this blood equilibrium we owe to the labor of many distinguished physiologists, but chiefly to Lawrence Henderson and van Slyke in America and to A. V. Hill and Barcroft in England. That is the second example I wished to mention. These two will suffice for my present purpose. What is the lesson to be drawn from them? No less than that the elementary phenomena of life are deterministic, that is to say, that events compensate or succeed each other just as in the physicochemical world of inanimate things, and that their compensations and successions can be exactly measured and expressed in the form of precise mathematical equations. Determinism exists just as much or, if you please, just as little, in the elementary phenomena of the living as in those of the nonliving systems familiar to physics and chemistry. Claude Bernard maintained that this was so. To the imperishable luster of his name be it said that 50 years of exact research have borne witness to the truth of his faith. Do not misunderstand me here. True science should have no dogmas. It would have been a wonderful and a fine thing if recent research in general physiology had led to a nondeterministic sequence of phenomena in the elementary condition of life. During the last 15 years theoretical physics, which has been undergoing a period of unexampled and daring advance, has dropped many a hint of the existence of apparently nondeterministic systems. The audacious springs of the electron within the atom from one energy level to another have often appeared to be ruled by considerations of relative probability rather than by any exact determinism in the ordinary sense of this word. But we can not as yet be sure of anything in modern theoretical physics. Just as we now hear little of the jumping frog of Calaveras County, so modern wave mechanics has overwhelmed the discontinuously jumping elec-

tron, and seems to offer more promise of determinism than did that uneasy ghost. Thus determinism in the rigorous sense of the word is no infallible dogma of science. It would not be surprising if it did not exist in the minute phenomena of the world, since the apparent determinism of events on a greater scale is often only the result of a very high degree of statistical probability. Be that as it may, the investigations of general physiology, so far pursued, indicate that the elementary phenomena of life are quite as fully deterministic as phenomena on a corresponding scale of magnitude in the inanimate physicochemical world.

Let us now make the daring supposition that general physiology, following the lead of Claude Bernard, has eventually succeeded in quantitatively analyzing every side and every aspect of the elementary condition of life. Would such a supposedly complete and quantitative analysis give us a synthesis of life? That is one of the most fundamental and difficult questions of biological science. A living being is a dynamically organized individual, all the parts of which work harmoniously together for the well-being of the whole organism. The whole appears to us as something essentially greater than the sum total of its parts. This aspect of the living individual was fully recognized by Claude Bernard. It has been emphasized recently by General Smuts in his remarkable book on Holism and Evolution. Life, as seen by General Smuts, is constantly engaged in developing wholes, that is to say, organized individualities. We may indeed learn how the regulative and integrating action of the nervous system, so beautifully and thoroughly investigated by that great physiologist, Sir Charles Sherrington, serves to organize and unite together in a harmonious whole the varied activities of a complex multicellular animal. We may learn, too, how those chemical substances, the hormones, discovered by Bayliss and Starling, are secreted by the ductless glands and, circulating in the *milieu intérieur* of an animal, act as powerful means for harmoniously regulating and controlling the growth and other activities of the various organs and tissues. Nevertheless, in spite of these great discoveries, the harmonious and dynamic correlation of the various organs and tissues of a living organism ever confronts us as one of the great mysteries of life. In an inanimate physicochemical system we think, if we know the situations, modes of action and interrelations of the component parts, whether particles or waves (or both), together with the boundary conditions of the system, that we have effected a complete synthesis of the whole. Though very crudely expressed, some such view as that lies at the basis of the Newtonian philosophy which rules our thought in the inanimate physicochemical world. Is the organized dynamical unity of a living organism something fundamentally new and different? Confronted by a problem of this order of difficulty, it behooves us to be patient and to

await the future progress of scientific research. Perhaps if we could actually witness and follow out the varied motions and activities of a single complex chemical molecule in a reacting medium we might find something not so very different from life. Or perhaps the organic unity of a living organism requires for its understanding some such explosion of human thought and inspiration as that which occurred when Einstein and Minkowsky discovered the true relations of what we call space and time. We may, however, be sure of this. The understanding, when it comes, will consist in something that permits of exact measurement and of precise expression in mathematical form, even though for the latter purpose a new form of mathematics may have to be invented.

Leibnitz once remarked that "the machines of nature, that is to say, living bodies, are still machines in their smallest parts ad infinitum." Anatomy and histology have progressively disclosed the structure of living things. Histology has revealed to us the cell with its nucleus and cytoplasm as the apparently fundamental unit of all the organs and tissues of a living being. What is contained within the membrane of a living cell? Here we approach the inner citadel of the mystery of life. If we can analyze and understand this, the first great problem—perhaps the only real problem—of general physiology will have been solved. The study of the nature and behavior of the living cell and of unicellular organisms is the true task of biology to-day.

The living cell contains a system known as protoplasm, though as yet no one can define what protoplasm is. One of the fundamental components of this system is the class of chemical substances known as proteins, and each type of cell in each species of organism contains one or more proteins which are peculiar to it. Important components of the protoplasmic system are water and the chlorides, bicarbonates and phosphates of sodium, potassium, and calcium. Other substances are also present, especially those mysterious bodies known as enzymes, which catalyze the various chemical actions occurring within the cell. Strange to say, the living cell contains within itself the seeds of death, namely those so-called autolytic enzymes, which are capable of hydrolyzing and breaking down the protein components of the protoplasm. So long, however, as the cell continues to live, these autolytic enzymes do not act. What a strange thing! The harpies of death sleep in every unit of our living bodies, but as long as life is there their wings are bound and their devouring mouths are closed.

This protoplasmic system exists in what is known as the colloid state. Roughly speaking, this means that it exists as a rather fluid sort of jelly. There is something extraordinarily significant in this colloid state of the protoplasmic system, though no one as yet can say what it really means. Recollecting the statement of Leibnitz,

one may be sure that the protoplasmic system of the cell constitutes a wonderful sort of machine. There must exist some very curious inner structure where the protein molecules are marshaled and arrayed as long mobile chains or columns. The molecular army within the cell is ready for quick and organized action and is in a state, during life, of constant activity. Oxidation, assimilation and the rejection of waste products are always going on. The living cell is constantly exchanging energy and materials with its environment. The apparently stationary equilibrium is in reality a kinetic or dynamic equilibrium. But there is a great mystery here. Deprive your motor car of petrol or of oxygen and the engine stops. Yes, but it doesn't die, it does not begin at once to go to pieces. Deprive the living cell of oxygen or food and it dies and begins at once to go to pieces. The autolytic enzymes begin to hydrolyze and break down the dead protoplasm. Why is this? What is cellular death? The atoms and the molecules and ions are still there. Meyerhof has shown that the energy content of living protein is no greater than that of dead protein. Has some ghostly entelechy or vital impulse escaped unobserved? Now it is just here, at the very gate between life and death, that the English physiologist, A. V. Hill, is on the eve of a discovery of astounding importance, if indeed he has not already made it. It appears from his work on nonmedullated nerve cells and on muscle that the organized structure of these cells is a chemodynamic structure which requires oxygen, and therefore oxidation, to preserve it. The organization, the molecular structure, is always tending to run down, to approach biochemical chaos and disorganization. It requires constant oxidation to preserve the peculiar organization or organized molecular structure of a living cell. The life machine is therefore totally unlike our ordinary mechanical machines. Its structure and organization are not static. They are in reality dynamic equilibria, which depend on oxidation for their very existence. The living cell is like a battery which is constantly running down, and which requires constant oxidation to keep it charged. It is perhaps a little premature at the present moment to say how far these results will prove to be general. Personally, I believe that they are of great importance and generality, and that for the first time in the history of science we begin, perhaps as yet a little dimly, to understand the difference between life and death, and therefore the very meaning of life itself. Life is a dynamic molecular organization kept going and preserved by oxygen and oxidation. Death is the natural irreversible breakdown of this structure, always present and only warded off by the structure-preserving action of oxidation.

The last great problem which I shall venture to consider in this brief sketch concerns the origin of life. It might indeed be argued

with much justice that such considerations are so far beyond the present stage of science that they are entirely without value. That, I think, is a bad argument and a worse philosophy. But, in any case, a dealer in mysteries is entitled to carry on his dealings as far and as best he may.

There appear to be two schools of thought in speculations of this character. The late Professor Arrhenius supported the theory or doctrine of Panspermia, according to which life is as old and as fundamental as inanimate matter. Its germs or spores are supposed on this view to be scattered through the universe and to have reached our planet quite accidentally. You will remember that Lord Kelvin suggested they were carried here on meteorites. But against this idea the objection has been urged that meteorites in passing through our atmosphere get exceedingly hot through friction with the air. Arrhenius brought forward the very ingenious idea that the motion in and distribution through space of these germs or spores were caused by the pressure of light, which in the case of very minute bodies can overcome the attraction of gravitation, as is often seen in the tails of comets. Many objections have been brought against this theory of Panspermia. It has been argued that either the cold of interstellar space or the ultra-violet light which pervades it would be sufficient to kill such living germs or spores. Certainly ultraviolet light is a very powerful germicide, though many spores can withstand very low temperatures for long periods of time. Perhaps the chief objection to this doctrine of Panspermia is that it is a hopeless one. Not only does it close the door to thought and research, but it introduces a permanent dualism into science and so prejudges an important philosophical issue.

If the living has arisen on this planet from what we regard as the nonliving, then various extremely interesting points arise. It is already pretty certain that it originated, if at all, in the primeval ocean, since the inorganic salts present in the circulating fluids of animals correspond in nature and relative amounts to what we have good reason to believe was the composition of the ocean some hundred million years ago. The image of Aphrodite rising from the sea is therefore not without scientific justification. We have seen that life requires for its existence a certain amount of free energy or nonequilibrium in the environment. In the early atmosphere there was plenty of carbon dioxide, and probably also some oxygen, though nothing like so much as at present. Volcanic action would provide plenty of oxidizable substances, such, for example, as ammonia or sulphuretted hydrogen. As we have seen previously, certain bacteria could therefore, in all probability, have lived and assimilated carbon dioxide, producing organic substances such as sugar and proteins. This argument, though very interesting from the point of view of Panspermia,

has a serious flaw in it from the present point of view, since the bodies of these bacteria would necessarily contain the complicated organic proteins of the protoplasm. When the earth cooled down to a temperature compatible with life, it is probable that the ocean contained little, if any, of such organic substances or their simpler organic components. There was likewise no chlorophyll present to achieve the photochemical assimilation of carbon dioxide. Hence the necessity of considering how organic substances could have arisen by degrees in a primeval ocean originally containing only inorganic constituents. The late Prof. Benjamin Moore took up this question and endeavored to prove that colloidal iron oxide in the presence of light, moisture, and carbon dioxide, could produce formaldehyde, a substance from which sugar can be derived. This work of Moore's has been actively taken up and developed by Professor Baly in recent years. He has conclusively proved that, in the presence of light, moisture, and carbon dioxide, formaldehyde and sugar can be produced at the surface of certain colored inorganic compounds, such as nickel carbonate. We may therefore conclude that the production of the necessary organic substances in the primeval ocean offers no insuperable obstacle to science. But there is still a very great difficulty in the way, a difficulty that was pointed out by Professor Japp, I think, at a former meeting of the British association in Dover. The protein components of the protoplasmic system are optically active substances. As is well known, such optically active substances, i. e., those which rotate the plane of polarization of polarized light, are molecularly asymmetric and always exist in two forms, a dextrorotatory and a levorotatory form. Both these forms possess equal energies, and so their formations in a chemical reaction are equally probable. As a matter of fact, chemical reaction always produces these two forms in equal quantities, and so the resulting mixture is optically inactive. How, then, did the optically active protein of the first protoplasm arise? In spite of many attempts to employ plane or circularly polarized light for this purpose, chemists have not, so far as I know, succeeded in producing an asymmetric synthesis, i. e., a production of the dextrorotatory or levorotatory form, starting from optically inactive, that is to say, symmetrical substances. The nut which Professor Japp asked us to crack has turned out to be a very hard one, though there is little reason to doubt that it will be cracked sooner or later. Even were this accomplished, very formidable difficulties still remain, for we have to imagine the production of the dynamically organized and regulated structure of living protoplasm. Professor Guye of Geneva has in recent years offered some very interesting considerations concerning this difficult problem. According to the statistical theory of probability, if we wait long enough, anything that is possible, no matter how improbable, will happen. All the ordinary

events of life happen frequently because they are very probable, whilst the improbable things happen on an average relatively rarely. The celebrated problem of the "typewriting monkeys" may be cited as an example. If six monkeys were set before six typewriters and allowed to hit the keys at their own sweet will, how long would it be before they produced—by mere chance—all the written books in the British Museum? It would be a very long, but not an infinitely long, time.

Now the second law of thermodynamics, to the scrutiny of which we subjected the phenomena of life, is purely a law of statistical probability. The odds against Mr. Home, the celebrated medium of former days, levitating without any compensating work or energy effect, are enormously heavy. The uncoordinated energy in and around Mr. Home might indeed spontaneously convert a part of itself into the coordinated energy of Mr. Home rising majestically into the air, but the safe odds against that happening are simply terrific. The ordinary large-scale happenings of the world, with which we are so familiar, are simply events where the odds on are gigantically enormous. The coming down of Mr. Home with a bump is an event on which we could safely bet, with an assurance of success quite unknown in racing or roulette. The theory of probability tells us that there always exist fluctuations from the most probable event. In the physicochemical world of atoms, molecules, and waves these fluctuations are ordinarily imperceptible, owing to the enormous number of individuals concerned. In very small regions of space, however, these fluctuations become important, and the second law of thermodynamics ceases to run. We have seen that the structure of living protoplasm is extraordinarily fine and delicate. Do events happen here which are to be classed as molecular fluctuations, or even as individual molecular events, rather than as the mass probabilities which have led men to formulate the second law? Something of that sort was probably in the mind of Helmholtz when he doubted the application of this law to the phenomena of life, owing to the fineness of the structures involved. The reasoning of Guye bears rather on the origin of life. Is the spontaneous birth of a minute living organism, he asks, simply a very rare event, an exceedingly improbable fluctuation from the average? This is a fascinating point of view, but it possesses one drawback. What is there to stabilize and fix this rare event when it occurs? Guye has himself realized this difficulty, but it may not be an insurmountable one. Such rare fluctuations may occasionally cause matter and energy to arrive at peculiar critical states where and whence the curve of happening, the world space-time line, starts out on a different path, and a new adventure arises in the hidden microcosmos.

If life has sprung from the nonliving, its earliest forms must have been (or must be?) excessively minute. We must look for these, if

anywhere, in those queer things that the bacteriologists call the "filtrable viruses." These are living bacteria so exceedingly small that not only are they invisible in the finest microscopes, but they pass easily through the minute pores of a Chamberland porcelain filter. D'Herelle has recently discovered the occurrence in certain bacterial cultures of what he calls the "bacteriophage." These seem to be excessively minute organisms which can hydrolyze certain ordinary bacteria. They constitute an extremely fine and filtrable "virus." Quite recently Bechhold and Villa, in the Institute for Colloid Research at Frankfurt, have devised a new and ingenious method whereby these minute organisms can be rendered visible and measured. The process consists in depositing gold on them, strengthening up these gilded individuals as one enlarges the silver particles in an insufficiently exposed negative, and obtaining as end result a sort of metallic skeleton of the original organism. It appears that the individuals of D'Herelle's bacteriophage are small disks whose diameter lies between 35 $\mu\mu$ and 100 $\mu\mu$. Now the diameter of an ordinary chemical molecule is of the order of 1 $\mu\mu$, i. e., one-millionth of a millimeter. Colloid particles are much bigger than that. If it be proved beyond all doubt that they are really living organisms, then the individuals of D'Herelle's bacteriophage are comparable in size with known colloid aggregates of nonliving matter. This result gives rise to strange hopes. If we can find a complete continuity of dimensions between the living and the nonliving, is there really any point where we can say that here is life and there is no life? That would be a daring and perhaps a dangerous theme to dwell on at the present time. But where there is hope there is a possibility of research. And who will set a limit to the discoveries that are possible to science in the future?

I hope no reader of this meager sketch of mine will call me a materialist or a mechanist. All I have endeavored to show, however briefly and inadequately, is that the sincere and honest men who are advancing science whether in the region of life or death are those who measure accurately, reason logically, and express the results of their measurements in precise mathematical form. A hundred or a thousand years from now mathematics may have developed far beyond the extremest point of our present-day concepts. The technique of experimental science at that future date may be something undreamed of at the present time. But the advance will be continuous, conformal, and homologous with the thought and reasoning of to-day. The mystery of life will still remain. The facts and theories of science are more mysterious at the present time than they were in the days of Aristotle. Science, truly understood, is not the death, but the birth, of mystery, awe, and reverence.

THE TRANSITION FROM LIVE TO DEAD: THE NATURE OF FILTRABLE VIRUSES [1]

By A. E. Boycott, D. M.

Rutherford was an example of the danger and folly of cultivating thoughts and reading books to which he was not equal. It is all very well that remarkable persons should occupy themselves with exalted subjects which are out of the ordinary road, but we who are not remarkable make a very great mistake if we have anything to do with them.—W. Hale White, preface to the second edition of *The Autobiography of Mark Rutherford.*

Pathologists are such practical people that I feel that I am straining the privilege of a presidential address about as far as it will go in attempting to discuss such a topic as the relation between things which we call alive and things which we call dead. But, though we seldom have opportunities of talking about them, we all have our speculative moments when we wonder about things in general and try to put together some sort of lay figure on which we can hang the facts which interest us and see how they fit, and I should like to take this chance of getting rid of some of my own imaginings and sketching the Jemima on which they seem to look fairly presentable. And I do this in a gathering of pathologists because a good deal of light is thrown on the whole question of "live" and "dead" by the "filtrable viruses," "agents," "bacteriophages," and what not, in which we have been so much interested in recent years.

I do not propose to enter at length on the old controversy between vitalism and mechanism. Pathologists might with advantage have taken a greater share in it than they have, for it would take a hardened mechanician to maintain his faith in face of our daily experience of repair adaptation and all the other purposive compensations for injury of which the body is so abundantly capable. Unfortunately our facts have not been widely known to those who have felt inclined to discuss the question. As far as I can see, the attempt to "explain life by chemistry and physics" has completely failed. It was thought at one time that if only the microscope could be made to magnify

[1] President's address, section of pathology, Royal Society of Medicine. Reprinted by permission from the Proceedings of the Royal Society of Medicine, November, 1928. Published also, abridged and revised, in supplement to Nature, Jan. 19, 1929.

enough, we should see life going on; the present contempt for histology is, I suppose, a sort of revenge on the wretched limitations of the instrument. Hope was then transferred to biochemistry, which has done just what the microscope did—it has helped us enormously to understand the mechanisms of live things and not at all to explain life; let us hope that it will not sink to the same degraded position. But if vitalism has had the best of the argument, it has not led to a very profitable or a very satisfactory position. Vitalism is often mysticism, and (which is why mechanism has been so popular) any dualistic interpretation of the world is always repugnant to natural human instincts. But it is possible to escape dualism in another way, and I suggest that the vitalistic controversy in anything like the form it has taken during the last 40 years is out of date, that instead of emphasizing the differences between live and dead things we should make as much as we can of their similarities, and that instead of dividing the world into two distinct categories we should regard it as being made up of one series of units with properties which differ more in degree than in kind. This is not the mechanistic view, for we come to it, not by explaining live things by dead things, but by realizing that the characteristics of live organisms appear also in dead matter. While we have been waiting for life to be explained in terms of chemistry and physics, a good deal has been done toward stating chemistry and physics in terms of life. Of course, no "explanation" of either live or dead has been given; the behavior of an atom is just as mysterious as the behavior of a wasp, and neither "explains" the other any more than a trypanosome explains a whale. But it is something of a comfort if we can believe that at bottom they both behave in much the same way; we can have one lay figure instead of two, and if its coat and trousers are not made of exactly the same stuff we may find them in reasonable harmony with one another.

Picking up such rumors as he might of what is going on in other lines than his own, every biologist must have been struck by the curious familiarity of several of the conceptions which in this century have gone to start the revolution in atomic physics which has pulled the universe in pieces and has perhaps not yet quite succeeded in putting it together again. The ideas are familiar because they were originally biological—derived from the study of live things and applied to their explanation. Let me illustrate what I mean by some examples.

(*a*) It is one of the characteristics of life that it is exhibited by discrete units which we know as organisms. As Powell White says, there is no such thing as living matter, there are only live organisms, and in so far as they are alive 0.1 cow or 1.35 cabbage are impossibilities. The enterprising surgeon could, of course, easily make something which was structurally about three-quarters of a cow, and I

dare say, even less, but what was left after he had done with it would be either a cow or not a cow—its essential cowness can not be other than integral. The live world is made up of such discontinuous pieces; so, we now learn, is the dead world. The notion that all matter is particulate is of immemorial antiquity, and as we go further in its ultimate analysis we come always to particles of ever-decreasing size; fractional atomic weights are as impossible as fractional animals; the quantum theory tells us that energy is also parceled out in bits; light consists of particles and, though the ether dies hard, the belief that there is anywhere a continuum—something without a grained structure—has been almost entirely abandoned. Discontinuities—in the structure of atoms and in the sizes of the stars—are now as characteristic of the dead world as of the live.

(*b*) When Rutherford and Soddy made people believe that one element really could be derived from another, they did for dead things what Darwin had done for live things; indeed they did rather more, for they backed their proposal with experimental proof which neither Darwin nor anyone else had produced in the biological sphere. In neither instance was the idea wholly new; suggestions of various kinds had adumbrated the change. "Evolution" was originally used in reference to the cosmos, but it was from zoology and botany that it spread through the descriptions of all human experience before it was applied to what had been supposed to be the ultimate verities of matter. And now, neglecting the time factor, chemical elements are not necessarily more stable than zoological species. For practical purposes lead is lead and a dog is a dog, but now we have to apply to both the reservation that they have not always been so, and can not be trusted to be so indefinitely in the future.

The disintegration of the radioactive elements takes place automatically: it can not be started, stopped, controlled, or modified; its progress is simply a question of the lapse of time. The modes by which organic evolution has been supposed to take place are beyond our discussion, but it is not impossible that it follows the same plan. Osborn and other experts hold that the course of any evolutionary sequence of animals is predetermined from the beginning; this "orthogenesis" may be interfered with by circumstances and opportunities, for live organisms are obviously liable to meet conditions in this world which they can not resist, and which may deflect them from a predestined track or bring them to an end altogether; dead elements meet their difficulties elsewhere in the universe.

(*c*) The classification of the elements which have developed by this evolutionary process recalls the familiar schemes of botanists and zoologists which show at once the affinities of animals and plants to one another and (though here there is of course a certain amount of guess work) their phylogenetic relationships. Animals were originally

classified by characters which we now believe to be largely immaterial—size, shape, habitat, and any other obvious features; Mr. Gladstone thought whales were fishes and bats birds, and plenty of people still suspect a slowworm of being a snake. About 150 years ago comparative anatomy began to get them into more natural groups, and evolution added the criterion of descent in determining the system which prevails at present. Much the same has happened in classifying the elements into something better than a series of arbitrary pigeonholes. Their discovery was the first step, much more difficult than the apprehension of animal species. The progress of chemistry then showed that they fell into groups akin to vital genera or families or phyla (we can not guess at what level the analogy is closest), and the discovery of inorganic evolution and isotopes has brought their relationships to a suggestively biological position. Atomic weights are no longer of any great importance; what matters in classifying an element is its atomic number which determines its position in the periodic table and is a summary of its comparative anatomy and a clue to its history. An element (e. g., lead) may arise by more than one line of descent, which is what a biologist would call "evolution by convergence." The isotopes into which Aston has dissected many of the elements correspond to the groups of closely allied species which embarrass the systematist and with which bacteriologists are familiar enough. Perhaps if they had sugar reactions or could be agglutinated, or indeed had a few more perceptible characters of any sort they might be easier to distinguish.

(*d*) If a man and a bicycle are smashed up together in a common catastrophe, the man mends himself, the bicycle does not. This capacity of self-repair is one of the greatest characteristics of live organisms; indeed, if one wishes to define shortly the subject matter of pathology I doubt if one can do it better than by saying that it is the study of how organisms resist and repair injury. They repair themselves in two ways. In the larger, more complicated animals we find very highly developed a capacity for individual repair which we see daily in the post-mortem room and experience continually in our own persons; it is so common that we are not impressed by it as much as we should be. Simpler things, such as bacteria, have little of this power of personal repair; indeed, I doubt whether a unicellular organism under natural conditions can effectively repair and recover from a substantial injury any more than can the individual cells of higher animals. But they achieve the same ends by other means, and owing to their numerical abundance and their high capacity for reproduction they can allow the injured individual to perish and readily replace him with a new one. Individually or racially, therefore, organisms repair themselves. Atoms seem to be able to do the same. All gross matter is made up of atoms, each of which

has a definite structure according to its species; as nucleus there are so many hydrogen atoms with their attendant electrons and outside are so many planetary electrons. Electrons are continually being detached from atoms by various means, e. g., whenever electrical energy is manifested. Presumably an atom of, e. g., iron which has lost an electron is no longer of its normal nature and substance, i. e., it has ceased to be perfect iron, and such a process would in the end lead to the iron becoming manifestly something which was not iron unless some restorative process was at work. It seems clear that injured atoms must be able to pick up electrons from somewhere to replace those which have been lost, a method of individual repair which appears to be efficient enough.

(*e*) Another of the great characteristics of live things is their variability. Any measurable quantity of any organism varies, and the values are distributed in some mode akin to the normal curve. Crookes suggested long ago that atoms vary in a similar way, Karl Pearson has imagined a world where contingency replaces cause and effect, and Donnan has emphasized that our chemical and physical constants are statistical, derived from the measurement of an infinite number of individuals, and summarizing, perhaps, the average values of a variable population. If biological measurements were made on the same scale, zoology and botany and even pathology might be "exact sciences" too. When we say that the atomic weight of one of the chlorines is 35, or that the mass of the hydrogen atom is 1.650×10^{-24} grm., it may tell us no more about the individual atoms than a statement that the height of the members of this section of the Royal Society of Medicine was 5 feet 8 inches would give us a view of the range of sizes which we represent. Whether atoms and molecules vary like organisms, therefore, we do not know—nor is it easy to imagine how we could find out. The possibilities of variation evidently become greater as structure becomes more complex—as we go, that is, from electrons to elaborate chemical compounds.

(*f*) Cane sugar boiled with dilute hydrochloric acid is progressively hydrolyzed till practically none of it is left. Analysis of the course of the reaction shows that (say) one-fifth of the original quantity is decomposed in the first five minutes, one-fifth of what remains in the next five minutes, one-fifth of what remains in the next five minutes, and so on until the amount left is inappreciable. This strange behavior is accounted for by assuming that the molecules of cane sugar go through some sort of regular rhythmical change, so that at any moment only a certain proportion of them are susceptible to the action of the water at the instigation of the acid. There is, I believe, no other justification for the assumption than that it fits the facts, and it can not fail to remind us of the rhythmical alternations of rest and activity which are common, perhaps universal, in live organisms. If, as Chick

has shown, bacteria sometimes succumb to heat or disinfectants on the same kind of plan, it is legitimate to say that they behave like the molecules of cane sugar. But it is equally correct to say that the molecules of cane sugar behave like bacteria. We can not tell which is imitating the other; all we see is that the behavior of both is similar. The conduct of the bacilli could hardly have been predicted from a knowledge of what happened to the cane sugar. The natural supposition would have been that the molecules of which each bacillus was made up would have been destroyed logarithmically, so that the death point of all the bacilli would have been reached simultaneously—a reflection which illustrates particularly clearly the considerable truth that the discrete unit which is comparable with the molecule of cane sugar is the whole bacillus and not one of its constituent molecules.

Now, I do not want to push these analogies between atoms and organisms too far, nor indeed to claim more than that they are suggestive to an imagination which is not afraid to have its wilder moments. Atoms are very much smaller, and necessarily of much simpler structure and functions, and one would no more expect to find in them all the qualities of organisms fully developed than one would look for all that goes to make a human being in the tubercle bacillus. However, it is only because we are used to it that we accept, without emotion, the idea that an amœba is analogous to an elephant; it must have been an amazing notion when it was new. There are two general objections which will probably occur at once to most biologists: (1) That dead elements do not show the multiplying reproduction characteristic of organisms; (2) that organic evolution on the whole progresses from the simple toward the complex, whereas what I have called the evolution of the elements proceeds uniformly in the opposite direction. The two difficulties are rather closely related.

Organic reproduction does two things: It produces a fresh version of the old organism and it gives an opportunity for numerical increase; its final effect is to leave organisms very much where they were. Each foxglove plant in my garden goes to immense trouble to produce about 500,000 seeds, and the wasps toil earnestly all the summer to increase from 1 to about 1,000. But next year there will be just about as many wasps' nests as this and just about as many self-sown foxglove plants. Darwin taught us the qualitative importance of this superabundance, but, quantitatively, it is made use of only if conditions alter; it then enables organisms to fill up any gap in the environment. If my wife interferes with the natural competition among the young foxgloves we may have more or less than last year; the vacant spaces in Bloomsbury have given us more willow herb than we had before the houses were pulled down, and when some phil-

anthropist enables the university to put up Dr. Maxwell Garnett's skyscraper we shall have less; we make a gap for bacilli in our culture tubes and they multiply as they never did outside. Man alters his own circumstances. These catastrophic alterations in numbers are flaring examples which attract attention. Slower secular changes in environment have the same effect, some sorts increase, others diminish, and on the whole there may be a tendency for a few large organisms to be replaced by many small ones. But, taking the facts as a whole, the capacity for reproduction does not result in more organisms than there were before; it merely enables them to adapt themselves to varying conditions. If organisms were less complicated, more stable and enduring, less easily injured, and if natural selection turned out to be a fact of experience without perceptible significance, the reproduction of organisms in general might be reduced to the level at which it runs in men in England to-day—numbers are just maintained. And if they lived longer it might be a still less important feature of their activities; an elephant does not bother about reproduction till it is 40 years old or thereabouts, a bacillus does it at an age of about 25 minutes. It will, however, need a vast increase in longevity if any approximation is to be made to the position in the dead world as we see it on this earth. It is indeed possible that there is here a real qualitative distinction between live and dead, but it seems more likely that the difference is one of mechanism rather than result, and, as we learn from biology, it is results rather than mechanisms which are important. With increasing complexity we get diminishing stability, which is presumably why there is no known element heavier or with a more elaborate structure than uranium. Units which are more complex can not maintain themselves without the periodical remaking which we call reproduction; those which are less complex do not reproduce, because they have no need to do so.

There is no reason to suppose that anything so like organisms as to deserve the same name exists anywhere in the universe except on the earth; as far as live things are concerned there is no need to look further. But we can not confine our speculations about dead things within the same limits. The stars are made of much the same elements as the earth, and material transfers take place in both directions; meteorites come and nearly all the hydrogen and methane which arises from the decomposition of cellulose by bacteria and streptothrix flies off to celestial bodies which are dense enough to secure their permanent adherence. The relevant habitat of the elements is therefore the universe and, taking this into consideration, it is not altogether clear that something like reproduction does not go on in dead things.

Though the elements seem inert and stable enough here and nothing much happens to them except the slow decomposition of those which

are, in our environment, radioactive, in the immense heat of the stars atoms not only come to pieces and are dissociated into protons and electrons, but their basic structure is destroyed, positive and negative electrons fall into one another, and matter is converted into radiation. In the heavens the elements disintegrate more completely than a dead cat does on earth, and unless there is somewhere some reconstruction the cosmos is coming to a material end. Lodge and Millikan think that in the depths of interstellar space, under conditions of intense cold, energy may once again become matter, radiation be reconverted into electrons which in their turn are recombined again into atoms, and so the various elements are reproduced; Jeans doubts any such regeneration. The duty of a pathologist does not call upon him to interpose his private judgment in so nice and important a controversy, and it would be impudent to say more than that some such process would enable us to have a comfortable faith in the maintenance of the material universe. If reconstitution is shown to take place, one can not help thinking of the nitrogen cycle, and how it was once held as certain (I was taught it as a student) that combined nitrogen was continually and irretrievably leaving the live world which must therefore inevitably come to an end; we had not appreciated nitrifying bacteria and attached more importance to academic argument than to Moses's directions for fallowing arable land.

If the elements do go through such a cycle, it is possible that what we call their "evolution" is more analogous to the death and reproduction of organisms than to the progressive appearance of more complex forms. Very little of the cycle takes place in our own particular corner of the universe, to which the organismal cycle is limited, and it is conditioned by very different circumstances of time and space, but it has much the same result in that it leaves things where they were. Protozoa are the better for reconstitution without multiplication; perhaps atoms are too. On the other hand, the reconstituted atoms may easily be of different species from those out of whose débris they have been built up, and under conditions where any reconstitution can occur it is possible that atoms are made which are more complex than any of which we have direct knowledge. Perhaps, too, the inorganic cycle is more nearly parallel to the appearance, progressive evolution, and final disappearance of a group of animal forms which some writers have imagined to be the birth, growth, and death of an organism drawn out on an extended scale. I do not know.

Such are some of the ideas familiar in biology which have appeared in the explanations of our experience of what is not alive. As I have stated them, they are to some extent inconsistent with one another and they lead to no certain conclusion; they furnish, however, an

assemblage of concurring and converging probabilities which encourage one to think it possible that things which are alive and things which are not alive constitute in effect one series, beginning with hydrogen atoms and reaching up to man, and perhaps on to angels, not arranged in a continuous linear succession but on a scheme resembling the phylogenetic line of the animal kingdom. The units (or "wholes" as Smuts would call them) which make up the series are of progressively increasing complexity, structural and functional, and must be compared against one another as they stand, irrespective of their composition. A hydrogen atom, a molecule of albumin, a bacillus, a dog are comparable as such, and it is not necessarily of any moment that hydrogen is the basic stuff of all matter, that proteids are essential constituents of all live organisms, or that a mammal is made up of many bits, each of which is more or less like a unicellular organism; in no case is the behavior of the more complex whole simply the sum of the behavior of its constituents. Such a view satisfies our natural antipathy to a dualistic explanation of the universe and makes the old controversy about vitalism and mechanism largely unnecessary. It tells us nothing about the nature of life; by indicating that organisms are analogous to elements, it encourages us to think of life as being as insoluble as gravitation, to give up the attempt to make out what it is and, as Lovatt Evans recommends, to spend our time more fruitfully in studying its phenomena. If you like to be paradoxical, you can say that live things are dead, or if you prefer it, that dead things are alive. Both at bottom have much the same characters, and it is unlikely that any sharp distinction between them can be drawn.

We pose to ourselves the question: Is the bacteriophage (or Gye's cancer agent, or the virus of plant mosaic, or any other "virus") alive or dead? in the belief that we are asking a crucial question to which there is a definite obtainable answer which would solve our troubles. In doing so we put up one of those false antitheses which so often lead us astray. The difficulty in most scientific work lies in framing the questions rather than in finding the answers, and by the time we are in a position to know what the crucial question really is we have generally pretty well got the answer. In this case "live or dead" is a stupid question because it does not exhaust the possibilities. Our general notion of the structure of the universe leads us to expect that we shall meet with things that are not so live as a sunflower and not so dead as a brick, and a consideration of what we know about "filtrable viruses" and similar "agents" brings us to the conclusion that they represent part of this intermediate group. Let us see how far they conform with what are, in ordinary language, admittably "live" and "dead."

Size.—Essentially they are very small though just how small it is impossible to say. They must be ultimately particulate because all matter is so arranged, and from the readiness with which they are adsorbed on to appropriate surfaces the particles are presumably much larger than the molecules of simple salts. Passage through filters with pores of different sizes turns out to be a complicated and dubious method of measurement, and the effects of centrifugalization may depend more on the specific gravity than the size of the particles. They are invisible, and ultramicroscopy shows nothing in the infective blood of polyhedral caterpillar disease, at least down to $50\mu\mu$ (and probably down to $15\mu\mu$), which qualitatively and quantitatively can not be seen in normal blood. Levaditi says (in error according to Bedson) that herpes virus goes through membranes which hold back complement and tetanus toxin; it is possible to concentrate solutions of hæmoglobin in the centrifuge. Taking one thing with another and reckoning that some viruses are doubtless larger than others, an average diameter of about 25 $\mu\mu$ (0.025 μ) seems a reasonable assumption, about $\frac{1}{10}$ the diameter of the smallest bacillus, about the same size as the colloidal aggregates of dissolved hæmoglobin and with room for 200 to 400 proteid molecules.

Now it is characteristic of all groups of animals and plants that they have upper and lower limits of size.[2] There is no mammal, fish, mollusk, or insect which is not perceptible to the bare eye any more than there is any bacillus which can be seen without a magnifying glass. It is also in a general way true that there is nothing which has the properties which we commonly associate with bacteria which is not at some stage in its life visible with the highest powers of the ordinary microscope or en masse in culture, though of course, if rules of this kind were too absolute, they would imply a more anthropomorphic world than most people nowadays are prepared to flatter themselves with.

Frank bacteria and protozoa may have minute phases: Leishman showed long ago that the spirochæte of African relapsing fever might in the tick be invisible and filtrable and we can not reject the evidence that even the tubercle bacillus may exist in a similar state. But no definite bacillus is known which is much smaller than pneumosintes, and it seems likely that at a diameter of something like 0.25 μ (250 $\mu\mu$), i. e., somewhere about the limit of direct microscopic vision, there is a break in the series which runs continuously downward from the largest bacilli (which would be visible to the naked eye if they were 20 times as big as they are) just as the series of mammals stops at a weight of about 5 grams and the series of beetles at a length of about 0.5 mm. The largest *Bacillus megaterium* is some 25,000 times the bulk of *Dial-*

[2] See the table in Animal Biology, by J. B. S. Haldane and J. Huxley 1927 276, and Contributions to Medical and Biological Research (Osler Memorial), 1919, 1, 226.

ister pneumosintes, which is a relative difference of the same order as that between a pigmy shrew and a big man or between a laboratory guinea pig and a large elephant. *D. pneumosintes* is about 400 times the bulk of what we imagine to be an average virus, and if there are no large viruses (the organism of cattle pleuropneumonia being probably bacillary) there may be more than seems at first sight in our definition of the agents we are discussing, by the facts that they can not be seen and that they will pass through filters with very small holes—a system of classification which has often been laughed at, though it could be applied well enough to many animal groups.

Composition.—A diameter of 0.025 μ does not give much room or many facilities for complicated vital actions. We do not know what occupies that tiny bulk; we do not even know that viruses are mainly proteid. There would be room for a larger number of simpler molecules though it is doubtful whether in any simulacrum of life this would compensate for the absence of the unique combination of chemical flexibility and physical stability which proteids possess and without which, as far as we know, "life" does not exist. The antigenic quality of viruses is our only evidence that they contain proteid. Clinically and experimentally they confer a resistance to reinfection which is, in comparison with antibacterial immunities, singularly intense and durable, and is associated with antiviral properties in the blood serum. As against this we have, (1) that antiviral serum contains only a simple neutralizing principle like an antitoxin (and possibly not actually effective in vitro) and has no specific agglutinin precipitin or (this is very doubtful) complement-fixing immune body; (2) that it is doubtful (though hardly, I think more than that at present) whether it is still true to say that all antigens are proteid in nature; (3) that substances like diphtheria toxin and the substance which Murphy has separated from the Rous sarcoma seem to be proteids of rather a special and simple kind. Another point which may be germane is that the dose of virus used for infection makes much less difference in the result than it often does with bacteria. The infective units are evidently present in enormous numbers in, e. g., the vesicle fluid in foot-and-mouth disease which may be diluted 1 in 10,000,000 and still carry on infection. There is a minimum infecting dose, which shows that infection is due to something definite and not to magic, but once this is passed the rate at which the resultant illness develops and the degree to which it reaches are not much affected by giving 1,000 or 10,000 times as much. The big doses of bacteria which are often administered to animals contain bacterial substance by whole milligrams by which the symptons and course of the infection may be greatly influenced. The absence of such poisoning effects with large doses of virus may, of course, be due to the small quantity of virus substance which is given, but it quite possibly follows from its quality.

There is indeed no evidence that viruses contain or produce poisonous substances as do so many bacteria.

We can not, therefore, affirm that viruses differ radically in composition from, e. g., the typhoid baccillus—nor that they do not. We probably have no business to make an assumption either way.

Metabolism.—The attempts which have been made to demonstrate the production of carbon dioxide by viruses have failed, but the quantities involved are small and the technical difficulties large, so that we can not regard the evidence as conclusive. It seems, however, that if they have any respiratory exchange it must be at a much slower rate per infective dose than that of ordinary bacteria.

Stability and resistance to harmful agents.—Some viruses at any rate can retain their activity in vitro for several years. Some bacteriophages endure for a long time in bacteria-free filtrates; the Rous tumor virus can be kept almost indefinitely in dried tumor tissue. Others are more labile and are difficult to keep over a period of days. There is much the same variability as there is with bacteria and bacterial toxins; viruses as a class are not characteristically unstable, evanescent things.

A good deal has been made from time to time of their resistance to heat and protoplasmic poisons. Here again the results are very various and differ with the sort of virus and the conditions of experiment; there are no general rules. But there are a remarkable number of instances of viruses which have resisted temperatures up to 75° C., and treatment with chloroform, alcohol, ether, toluol, phenol, acids, alkalies, and so forth. Formalin destroys many of them quickly, which is curious, for its action in coagulating proteids is much slower than that of alcohol, which they often resist. As a whole they are certainly more resistant than vegetative bacteria, but it is not certain that they differ markedly from bacterial spores. In several particulars this resistance recalls that of enzymes, and their peculiarities may be another reason for suspecting that they are not made of quite ordinary proteids. There is nothing in their size per se which should protect them.

Capacity for independent life and multiplication.—There is no convincing evidence that any virus has grown and multiplied in artificial culture, though successes have been reported, and the observations of the Maitlands on vaccinia are difficult to explain away; they would have been more impressive if animal cells could have been kept out of the medium altogether. Living cells are in all cases necessary, which may be supplied by living bacteria, living animals or plants or tissue cultures. That they really do multiply under these conditions seems beyond question; indefinite serial passage of an infective virus (e. g., foot-and-mouth disease) through experimental animals (e. g., guinea pigs), indefinite subculture of the bacteriophage, quantitative tissue

culture of the Rous agent—indeed all the evidence we have is conclusive on that point. Viruses are certainly not enzymes. Apart from living cells they may for a long time survive, i. e., remain in such a state that, on altering the conditions, they can give rise to their characteristic effect—vaccinia, a sarcoma, bacteriolysis, etc. But there is no evidence that they multiply under these conditions, and multiplication at the expense of the environment is probably regarded by most of us as the most important criterion of life.

For their multiplication, young growing cells are especially suitable, and it may be quite necessary. The bacteriophage multiplies only with the multiplication of the associated bacteria, and vaccinia, herpes, Rous sarcoma, etc., develop and multiply especially in connection with the growth of cells which results from local injury. Cell injury and cell growth are so intimately related that I know of no case where cell growth can certainly be excluded, but at present we can not be quite certain that it is necessary. It seems also to be true that viruses multiply only in the course of the production of their specific effect.

But though the fact of multiplication is plain, it is by no means proved that it is effected in the way which is familiar in bacteria and living organisms generally. We put in so much virus and we get out more: We have no evidence, nor, I think, the right to assume, that the particles which we get out are the direct descendants of those we put in.

It may be that these facts are best explained by supposing that viruses are obligatory intracellular parasites, and that the difficulty of cultivating them on artificial media will be solved when we can imitate sufficiently closely the essential features of the intracellular environment; pathogenic protozoa were not cultivated at the first trial. Very few bacteria live inside animal cells, and it is perhaps significant that those that do (e. g., *Brucella abortus* and *Bacterium tularense*) are among the smallest of the group. Viruses have, of course, not been seen inside cells, but their dependence on living cells, and the considerable regularity with which their presence is indicated by cytoplasmic and intranuclear "bodies" (some of them of specifically characteristic appearances) make it quite likely that such a position is their natural habitat, in which they multiply and from which they spread, as they do, to other places, liquids, and secretions. This habitat might have something to do with the peculiarities of their immunological relations. Living within cells it is perhaps unnecessary for them to produce any definite toxins; mechanical disorganization of the cellular anatomy might well be the effective cause of the injuries they produce. The general symptoms of infections (headache, fever, prostration) are caused, as in bacterial infections, mostly by substances derived from the injured cells of the host,

and these would also account for part at any rate of any local inflammatory response.

Such an explanation would do quite well for the viruses that accompany infectious diseases and would cover the facts for the bacteriophage. But phenomena are known which are surely more or less analogous, and which it is hardly possible to regard as due to parasites of any kind.

There is, for instance, the agent which induces cells to become malignant, indicated years ago by the Imperial Cancer Research Fund (Haaland and Russell) when they showed that close contiguity with malignant epithelial cells might cause normal connective tissue to grow into a transplantable sarcoma—one of the great discoveries of pathology. People had known that they met with tumors occasionally which seemed to be mixtures of carcinoma and sarcoma; they knew, too, that the cells at the edge of small epitheliomas looked as if they were being transformed and were on the way to become malignant, though the prevalence of a curious dogma to the effect that this could not really be so generally prevented them talking about it. The experimental mouse work explained these appearances; without it they could have carried no serious inference that cancer cells might influence normal cells towards malignancy. Unless we suppose that tumor cells pervert neighboring normal cells by argument, persuasion, example, or some other sort of immaterial communication, we naturally assume that some substance passes out from the one to affect the other. All attempts to demonstrate this substance in dead tumor cells or in extracts of them uniformly failed until Rous came across his fowl sarcoma and showed that it could be transmitted indefinitely from bird to bird by dried dead cells or by filtrates which contained nothing that could be seen or cultivated. This particular tumor produces the substance in a form so stable that it can be examined and played with when it is detached from live cells. With most transplantable tumors it is present in such small amounts, or more likely in such a labile unstable form that its clear demonstration is not possible; the carcinoma-sarcoma experiment comes off only with a minority of mouse carcinomas. Gye has shown that its activity may be modified, enhanced, or depressed, by various conditions, which helps to explain the difficulties and apparent inconsistencies which are met with in its experimental investigation. But a fair number of tumors have now been transmitted by filtrates, and there is, I think, no reason to doubt that the production of this carcinogenic substance is a common property of all malignant growths. We believe that all pathogenic bacteria, or at any rate all the larger ones, produce extracellular toxins; there is no other way in which they can injure the tissues. But in many instances they are so unstable that it is at the best difficult to demonstrate their presence apart

from the bodies of the bacilli, and impossible to investigate them in detail. Nor should we, I think, be too shy of drawing general conclusions from such specially easy and demonstrative examples as Providence has provided for our learning and pushes under our noses, till even our stupidity is bound to take notice; diphtheria and tetanus for toxins, the guinea pig's peculiar bronchial musculature for anaphylaxis, mice and tar for tumors, radium are such signposts; the Rous tumor is another.

Another analogous phenomenon takes us, I think, a step further. The products of autolysis of dead cells in the body, in suitable concentration, stimulate tissue growth. It is a beautiful self-regulating mechanism in which the amount of stimulus is proportionate to the amount of cell destruction, and therefore to the amount of cell growth required, and it is obviously of the highest importance for survival—a far more potent factor in selection and evolution than any disease has ever been. As it normally operates in healing our cut fingers, the final result is simply the restoration of the cells which were destroyed. But if the normal restraint exercised by neighboring tissues is evaded and use made of tissue cultures, the products of autolysis or metabolism (in the form of extracts of tissues, tumors, or embryos) stimulate growth indefinitely and a much larger quantity of tissue may be obtained than we started with. From the autolysis of this a larger amount of stimulating substance may be obtained, and there seems no reason why this process of multiplication should have any limit. Normal tissues in the physical isolation of tissue cultures are as immortal as malignant tissues in their physiological isolation from the rest of the body.

No one would, I think, pretend that these products of autolysis are alive in any ordinary sense of the word. They have not received nearly as much attention as they deserve, but they are probably of relatively simple and discoverable constitutions. Yet applied to cells they cause growth, and in so doing potentially increase their own quantity; this is very much what the Rous agent does. There are, too, these further minor similarities: The Rous agent stimulates one particular type of cell (white fibrous connective tissue) to malignancy, some extracts of normal tissues stimulate fibroblasts in tissue culture while others act specially in epithelial cells; the activity of the Rous agent may be encouraged or depressed by the simultaneous presence of other tissue extracts, some tissue extracts inhibit growth instead of encouraging it.

But the chief importance of the analogy is, I think, in throwing light on the nature and origin of the Rous virus. If we agree to put the products of autolysis in the category "dead," by what difference are we to separate the Rous virus as being "alive"? It can not be

cultivated apart from live cells, it multiplies only under conditions where its specific activity is displayed, its inactivation by chloroform and other protoplasmic poisons does not take it nearer life than are toxins or enzymes or indeed simple metallic catalysts, and its retention of activity after the drastic methods of purification recently described by Murphy seems to definitely exclude it from "live." As to its origin, all the evidence seems to concur in indicating that the Rous virus arises de novo in each tumor. There is no epidemiological evidence that cancer comes into the body from outside; everything we know supports the classical view that it is a local autochthonous disease. Most of the experimental work with the virus has started with an actual tumor, and it is therefore just possible that an agent might be carried along through the whole series which originated somewhere else than in a tumor. But experimental sarcomas produced by embryo extract and indol, arsenic, or tar have been transmitted by filtrates, and if others have failed to reproduce Carrel's results I would only remark that in a question like this one positive experiment is worth more than a great many negative ones. Epitheliomas are easily produced in mice by tar and in men by chronic irritation, and if we believe that all malignant tumors contain more or less of a carcinogenic agent akin to the Rous virus, it follows that we can with a considerable degree of certainty stimulate normal tissues to produce virus. It is, therefore, not very remarkable that Murphy, Leitch, and Brebner have at any rate occasionally demonstrated a carcinogenic agent in preparations of normal tissues (testes, pancreas, and embryo plus placental extract).

It is difficult to escape the conclusion that the Rous virus arises in the tumor. There is no doubt that it is a means by which a tumor may be experimentally dispersed through any number of available animals, and it is apparently responsible for some, at any rate, of the metastases which occur in the course of the natural disease. But there is no evidence that such a virus ever naturally causes a fresh tumor, and we learn the important lesson that the means by which a disease is propagated may not be the same as that by which it was originally started.

This consideration becomes particularly interesting when we try to bring a frankly infectious disease such as foot-and-mouth disease, measles, or smallpox into comparison. Brought up as we all have been in the heyday of bacteriology, it is a little difficult for us to get an unprejudiced view of the situation. Because an agent is constantly associated with and, as we believe, is the cause of a disease very similar to others which we feel assured are caused by bacteria, we naturally assume that its natural history is more or less similar to that of bacteria. We might have been in a better position to take a just view of the facts if we had lived in prebacteriological days, or if we could put

on some of the complexion of Charles Creighton's outlook and do our best to imitate his learning and industry.

The chief way in which the virus of, e. g., foot-and-mouth disease differs from the Rous agent, and, going, a step further back, from the products of autolysis (or metabolism) which stimulate growth, is that it seems to spread about pretty easily from one individual to another; chiefly, I think, from the parallel of bacteria we take this to imply the possibility of independent life and probably independent multiplication. But we have no direct evidence of this; all we know is that, like the Rous agent, it can be deliberately dispersed through any number of individuals indefinitely, and that it multiplies only when and where it produces its specific effect. The blister which is determined on the foot of an inoculated guinea pig by slight local injury is preeminently the place in the body where the virus is found in the largest amount, and, trying to be as open-minded as we can, we must allow that this may be due either to the lesion being produced where the agent is present in greatest quantity, or to the agent being produced in greatest quantity where the lesion is. You may say that if the guinea pig is inoculated with a filtrate, i. e., with nothing but virus, the lesion must be due to the virus. No doubt that is in a general way true, but it does not follow that the whole of what we call the lesion is due to the immediate and direct action of the virus. Local effects at the site of inoculation (if they occur) prove nothing; they may well be determined by the concomitant injury. Putting aside all bacteriological analogy, we have no proof that the particles of virus which we get out of the lesion are directly descended from those we put in. In other words, we have to reopen the question which most of us regard as settled: Is the agent the cause of the disease or is the disease the cause of the agent? Another stupid antithesis, for the alternatives are not mutually exclusive; both might be true.

From the time when Pasteur first began to persuade the world that microorganisms might be something more important and effective than microscopical curiosities, there have never been wanting nonconformists who have held that microbes were the result rather than the cause of putrefaction, fermentation, and disease. It is very difficult—indeed, it seems impossible—to believe in this thesis in respect of bacteria which can be shown to have an independent life by cultivation and which can be inoculated into an animal with the production of a definite disease (e. g., tuberculosis); the bacteria which we get out of the experimental lesion may without undue credulity be supposed to be the direct descendants of those which we have put in to produce it. But, as Hamer and Crookshank remind us, we have quite possibly gone too far in identifying a "disease" with its accompanying microbe and defining diseases in terms of what we believe to be their causative agents. If it is sound to do this (as it certainly appears to be) with

some epidemic diseases, it does not follow that the method can properly be applied to all of them. After all "similarity" between diseases is liable to be superficial; most of the clinical symptoms of infections are due to the reaction of the body, and on a priori grounds one would expect resemblance between diseases of quite diverse ætiology. I conclude, therefore, that we have to admit the possibility that, as in the Rous sarcoma, the viruses which we associate with certain diseases are not their original causes though they may be the means by which they are propagated and carried on.

You will probably say—and I think with a good deal of justification—that it is contrary to all common sense to suggest seriously that the viruses of diseases like smallpox, measles, or rabies arise anew in each infected person. And it may indeed be nonsense. It is evidently more conformable with our general experience and with the epidemiological dogma to which we subscribe to lay stress on the definite way in which each case can be traced to a preceding case and that to another, and so on, explaining such examples of apparently spontaneous origin as we meet with by carriers and the imperfections of our data rather than by the concurrence of a favorable epidemic constitution of the atmosphere. With that point of view I quite agree; the evidence that in an epidemic something is passed on from one case to the next seems extremely strong. But at the same time I can not altogether get rid of the uneasy suspicions which intrude when I think of, e. g., foot-and-mouth disease, distemper, or labial herpes.

Distemper seems to be everywhere where there are susceptible animals, and if the stock of dogs at Mill Hill can be kept free from it indefinitely it will be a point of much more than technical interest. As to foot-and-mouth disease, in which no material connection between one outbreak and another can be discovered, I think that the unbiased man in the street would say that the facts showed either that the virus was universally dispersed, possibly in some common animal (such as the hedgehog [3]) other than the cow, or that the disease was continually beginning afresh. Labial herpes seems in much the same position. Epidemics may be found by ransacking the literature but they are certainly not common. Not only has herpes no connection with itself but it has a definite association with other diseases—pneumonia and severe catarrhs; its possible relation to human encephalitis does not help us—both are blind men. It is possible that the virus is an offshoot from the pneumococcus, though when Perdrau looked for it in pneumonic lungs he found instead another "agent" which could be transmitted through rabbits in series.

[3] Mr. Charles Oldham tells me that at the end of the eighteenth and beginning of the nineteenth century churchwardens in Hertfordshire put as high a price (4d.) on the head of a hedgehog as on that of a polecat "Urchins" were supposed to do something to cows which diminished the yield of milk and this was translated into a belief, still extant, that they sucked the cow's udders when they were lying down. Such expenses were not lightly incurred in those days.

I daresay, however, that some simple explanation will be found for these epidemiological difficulties and that any suspicions that we may have about the origin of these viruses will be allayed. Viruses can remain dormant in live animals for a long time and carriers might be activated by a variety of incidents. But what are we to make of such a phenomenon as Virus III? Virus III is made manifest by inoculating a filtrate of an emulsion of a rabbit's testis into the testis of another rabbit. This procedure is sometimes followed by an inflammatory reaction and the production of intranuclear "bodies," and if this inflamed testis is emulsified and the filtrate inoculated into another fresh rabbit the inflammatory condition is reproduced; thereafter the "disease" can be carried on indefinitely. It is not fatal, and after his attack has subsided a rabbit is refractory to further inoculations and his blood serum can prevent infection with active virus. If we knew nothing of bacteriology, should we not conclude that the virus had been generated by our procedures from the tissues of the normal testis? The only evidence to the contrary is analogy, and the slender fact that the phenomenon comes off more easily in New York than in London rabbits. I do not know how many people have tried similar experiments with other apparently normal tissues; if they had been positive we should certainly have heard about them; Leitch's, Brebner's, and Murphy's successes with sarcoma have already been mentioned, and bacteriolysins transmissible in series have been extracted from normal organs.

It might be expected that what we know of immunity to these viruses would throw some light on their origin and nature, but as a matter of fact it does not seem to give us much help; as far as it goes, it is perhaps against their autochthonous origin. Two points are certainly clear. In susceptibility to reinoculation and in the neutralizing properties of the blood-serum, the immune reactions are at least as sharply specific as they are with most bacteria; some viruses show immunological races as bacteria do. The facts of natural immunity are also very similar; a virus may affect one, two, or several species of host and have special affinities for certain tissues. We might use this analogy, and the general proposition that immune reactions occur only if the antigen and the reacting animal are of different species, to argue that viruses must come from outside the affected animal, and to say, e. g., that if virus III originates from rabbit tissues it ought not to stimulate a rabbit to an antiresponse as it does. The argument seems to be rather a strong one, but it is not conclusive. It is easy to suppose that the virus, whatever its origin, would not have on it the stamp of complete rabbitness; considering its size and its other peculiarities it would perhaps be rather remarkable if it had. We know, too, now that the general immunological rule about specific differences and specific identities

has many exceptions. The lens of the rabbit's eye is antigenic to the rabbit and in common with such proteids as casein and egg albumin it is not species specific; a mother reacts to the blood corpuscles of her fœtus if they happen to belong to a different blood group; the development of one tar cancer makes all the rest of a mouse's skin refractory to the development of another, though whether the resistance is to the mouse's own malignant tissues or to a virus which has developed in them we do not know. One can hardly, then, I think, be sure that a virus has an extraneous origin because an animal treats it as an antigen.

Whatever filtrable virus we look at we meet with the same difficulties. A good many people are willing to believe that the bacteriophage is generated by its bacillus—which is probably the truth. And they would explain the way in which each bacteriophage more or less fits its own bacillus by its having originated from that bacillus. Others see in their multiplicity evidence that bacteriophages are really live organisms with the characteristic variability and adaptability. It is perhaps more than a coincidence that it is in another group of plants that the same difficulty has arisen: the agents of plant mosaic diseases have never been found apart from affected plants; they have not been cultivated; no one can be sure whether there is one virus or many viruses. Lysozyme is another phenomenon about which one would like to know more. It is widely distributed in animals and plants and is abundant in egg white; withstands drying, alcohol, chloroform, etc.; acts on dead as well as live bacteria, and would pass for an enzyme were it not increased in amount by dissolving *Micrococcus lysodeikticus*. Such multiplication during the exhibition of its activity seems to connect it with the viruses, but Fleming says that it can not be carried on by serial cultures.

If viruses do originate in tissue cells, what are we to imagine that they are? Béchamp's ghost would answer "microzymes, as I told you 70 years ago." Altmann would say bioblasts, others micellæ and even mitochondria, and all the people who have imagined that cells are made up of much smaller essential elementary live particles would see in the present development the fulfillment of their prophecies. They can not all have been exactly right; bioblasts are quite big, and mitochondria (which some have supposed to be symbiotic organisms) are also visible, and not only to the elect. But it may well be that they were making as shrewd guesses at the truth as Prout did when he suggested that all elements were ultimately compounded of hydrogen. Till Harrison did it we had not suspected that the cells of warm-blooded animals could be cultivated in vitro. If they can live and multiply, divorced from their proper community, is it altogether impossible that parts of cells might have something of a separate existence also just as electrons may operate apart from atoms? Granting that they might

why should they have such injurious effects? To which there are two answers: First, we apprehend only such disembodied parts of cells as produce some definite effect which we can observe, and, as it happens we have perceived only those which do damage; second, believing as the fundamental proposition of morbid anatomy that structure and function go hand in hand, we should naturally expect such gross aberration of structure to result in such a departure from the normal course of function as, in this so nicely adapted world, would manifest itself as injurious.

What to make of all this confused mass of facts and speculation I do not know. We seem to have a fairly definite group of things which, (*a*) are very small; (*b*) can multiply; (*c*) have no independent life; (*d*) are of uncertain origin. Of their multiplication we know that the association of live cells is necessary, and that it occurs when the specific effect of the agent is manifested; we do not know that direct multiplication is possible at all. Of their origin, we have strong grounds for thinking that some are derived from live cells and we can not exclude this ancestry for any of them. They seem, too, to form a series: (1) The growth-promoting substances from tissues show indirect multiplication but make no other suggestion of life; (2) lysozyme would pass for an enzyme except that it can multiply; (3) the Rous agent and the bacteriophage arise repeatedly in malignant tumors and bacteria, respectively, and may be in some sense alive, but they are not independent species of animals or plants; (4) the pathogenic viruses represent a further step toward being wholly alive. Taking one thing with another, I am inclined to think that they are both the cause and the result of their diseases as Sanfelice suggested for epithelioma contagiosum. Somehow or other a virus arises in an animal or plant and by its action on the tissues causes them to produce more of itself. Some viruses (e. g., smallpox) acquire a considerable capacity of spreading from infected to normal individuals and the majority of cases of the disease are so caused; the virus is on the way toward independence. Others (e. g., herpes) have little or no power of dispersion and most cases are due to the virus arising de novo under the appropriate stimulus (whatever that may be). You may say that if that is so it is strange that one case of herpes is so like another and that epidemic virus diseases are so uniform in their characters and so "true to type." It is, indeed, rather curious, but the circumstances which lead to the generation of a virus are presumably often repeating themselves, the possibilities of parts of cells having a separate existence are very likely limited, and after all the specific characters of infectious diseases are not always very sharply defined. However, these are difficulties which I am not prepared to solve; my object has been to ask questions rather than to answer them.

I have made no attempt to acknowledge the many sources, printed and verbal, from which I have derived facts and ideas.

HERITABLE VARIATIONS, THEIR PRODUCTION BY X RAYS AND THEIR RELATION TO EVOLUTION[1]

By H. J. Muller

University of Texas

Biological evolution is composed of a succession of individual variations, which, being heritable, become accumulated to form an increasingly complex living fabric. The long-disputed questions concerning the method of evolution can therefore be decided only through a study of the mechanism whereby these individual variations are produced. What is needed here is more precise and analytical data regarding the nature of those differences which distinguish one generation of individuals from its predecessors, and which they in turn tend to transmit as a heritage to their descendants. We must not remain content to view evolution from afar, but must view close up, as through a microscope, the transitions now occuring out of which the evolutionary story is pieced together. The science which essays this study is "genetics."

THE FUNCTION OF THE GENE

During the present century genetics, building upon the earlier discoveries of Mendel, has practically solved the problem of the method of inheritance of the differences referred to, once they have arisen. All modern genetic work converges to show that the heritable differences between parent and offspring, between sister and sister, in fact between any organisms which can be crossed, have their basis in differences in minute self-reproducing bodies called the genes, located in the nucleus of every cell. The genes themselves are too small to be separately visible, but hundreds or thousands of them are linked together into strings, and these strings of genes, together probably with some accessory material, are large enough to be seen through the microscope by the cytologist; they constitute the sausage-shaped bodies called chromosomes. We know that, ordinarily, each individual gene in a string is different from every other gene in the same string, and has its own distinctive rôle to play in the incomparably complicated economy of

[1] Based on an article in the Scientific Monthly, December, 1929; here printed by permission of that journal.

the cell. Moreover, the genes in different chromosomes are different from one another, except in the case of homologous or twin chromosomes, *i. e.*, the corresponding chromosomes which each cell of an individual received from the father and from the mother of the individual, respectively. To match each chromosome that was derived from your father, every cell of you has in it also a similar chromosome (though not necessarily quite identical) derived from your mother, so that it contains in all two complete sets of chromosomes and hence two complete sets of genes. The proper functioning of the cell during its life depends upon the proper cooperative functioning of its thousands of different genes. One complete set of genes would ordinarily be enough for this, but two sets are provided so that new combinations of the characteristics of different ancestors may be tried out.

Each given gene in the cell must of course have its own specific chemical composition, differing from gene to gene, though there is, no doubt, a chemical relationship between all genes. As yet, however, we have no knowledge as to what the chemical composition of any individual gene, or of genes as a group, is. Whatever it is, we can not escape the fact that the different genes, through differing chemical reactions with other substances in the cell, produce by-products which have a very profound influence upon the properties of the protoplasm. And through the combined influences of all the chemical products of the thousands of different genes in a cell, meeting one another in the common protoplasm and then interacting in devious ways to form further products again, the exact form and physical and chemical characteristics of all parts of the cell that contains those genes will be determined, for any given set of outer conditions. Changing conditions external to the cell will, of course, change the properties of the protoplasm, too, but what form and behavior it can and will show for a given set of outer conditions depends primarily upon what genes it has. Since the body of a man or other animal, or a plant, is made up of its cells, and the form and other properties of that body depend upon the properties of these constituent cells—their form, the way they fit together and work—it is evident that, less directly but no less surely than in the case of the individual cells, the characteristics of the whole body depend upon the nature of the genes in the individual cells.

These individual cells of the body have, during the development of the embryo, been derived from an original fertilized-egg cell, through a succession of cell divisions in the course of each of which every chromosome and every gene present in the dividing cell also divided in half, one half of every chromosome and gene then entering one of the two daughter cells and the other half entering the other daughter cell. Between divisions the chromosomes and genes usually had a

chance to grow back to their original size. Thus it results that every cell of the body has the same kinds and numbers of chromosomes and genes as the fertilized egg had, and as every other cell in the body has. The original two sets of genes of the fertilized egg—one set received from the sperm of the father, the other similar set derived from what the egg of the mother contained before fertilization—are still both present in every cell of you. But these two sets of genes of the fertilized egg were all, and more, that were needed to result in a complete man. We see, then, that every single cell of you in the skin, the brain, or anywhere else, contains the makings of a complete man or woman, and that you are in this sense wrapped up within yourself many trillion fold. Not each cell may grow up into an entire man, of course, but must remain content to do its specialized share, even though it has a full cargo of genes, because its structure and activities are limited and regulated in various ways through the mutual influences received from the other cells in the body. The various cells of different organs developed differently from one another because, though possessing the same genes, they found themselves in different situations subject to different influences from the start. Only the egg and sperm cells then may eventually realize anything like their full potentialities.

All this explanation, somewhat off the main theme, will serve to furnish some notion of how the characteristics, in fact the entire substance, of any human or other living being depend upon its genes, acting in a chemically coordinated fashion. So complicated is the manner in which the products of the different genes react with one another that no final product and no characteristic of the adult body is due to any one specific gene, but in the production of every organ, tissue, or characteristic, numerous genes take part. Nevertheless, if one individual differs from another individual in regard to just one of the genes that do take part, it will be seen that the given characteristic in the two individuals will be different, and so, conversely, a difference between two individuals in regard to a certain characteristic, let us say eye color, may be due to a difference between just two given genes in them rather than other genes. We may then call these for short the genes "for brown" and "for blue" eyes, respectively, while remembering that really in both individuals many other genes are present also which are helping to produce the exact eye colorations seen, but that these other genes happen to be alike in the two individuals in question, and therefore are not causing this particular difference between this brown eye and this blue eye.

By studying the characteristics that appear among the descendants in later generations, after individuals differing in regard to one or more genes have crossed together, the definite Mendelian laws and the laws of linkage, governing the handing down of genes from one generation

to another, have been determined, and they are found to have a practically universal validity. There is no use attempting here to formulate in deta.. these rules and their working out. Most of modern genetics has been occupied with tracing down these "facts." They relate essentially to the method of transmission, to later generations, of gene differences that are already found to exist between individuals. They show the universality of these differences, their comparative permanence, and their recombining capabilities (as when a man derived, several generations back, from a mixture of European and Indian blood exhibits the coloration of the European and the broad face of the Indian). But they leave untouched what now becomes the major question—how do such differences originate in the first place? What is the origin of variations?

THE FINDING THAT THE GENES MUTATE

A hitherto rather incidental, yet very important part of modern genetics has had to do with this latter problem. It has been discovered definitely that such differences do arise, de novo, as it were. That is, not all the gene differences now existing in a population have existed in it from the beginning. New differences are continually arising somehow, and the differences now existing have undoubtedly arisen in the past in a manner similar to these.

Each gene difference arises suddenly and full fledged, though we may not be aware of it at once. Thus, in a population of gray-colored mice, suddenly in a certain cell of one individual, one of the genes whose cooperation is necessary for the production of the gray color undergoes a change into a gene of different composition that tends, in its interaction with the other genes for color, to produce a yellow tinge instead of gray. In this single cell, however, the change will not be observed by us. But if this cell, or one of the cells derived from it, happens to be a germ cell, an offspring individual may be formed in the next generation, all of whose cells may carry this new gene. Then if the new gene is dominant (as it happens to be in the case of yellow and gray in mice) to the old gene for gray which the offspring has received from its other parent, the coat of the new animal will be yellow, and we will see that a mutation has occurred. But if the new gene had been recessive (i. e., if the gray was dominant) the offspring would have appeared gray like its parents and we should not have been aware of the mutation. The new gene might persist none the less, and be inherited by generation after generation in invisible fashion, being meanwhile "dominated over" by the gray from the other parent. If in a later generation two descendants both of which carried the mutated gene happened to mate together, an egg with the yellow might become fertilized by a sperm also carrying yellow, neither, therefore, carrying the dominant

gray, and from such a union a visibly yellow offspring would emerge for the first time. A mutation, when recessive, may accordingly fail to manifest itself for many generations, or may never have a chance to show itself at all, before the line of individuals carrying it becomes extinguished. (It has been shown by Fisher that most mutations must meet this mute inglorious fate.)

The new gene, once it has arisen, is ordinarily as stable as the old. The change is definite and fixed, obviously of a chemical nature. Once it has occurred we have a new mutant gene which will either spread throughout the population or be killed off, according as the individuals which carry it reproduce more offspring or fewer. The effects of mutations are of course as varied as the gene differences which are found to occur within populations, since these gene differences originated by mutation. Some gene differences, some mutations, produce large and startling effects, like growing a leg on a fly's forehead. Some affect the whole body in practically all its parts, others change two or three characters, others apparently but one. But the less conspicuous changes, the insignificant effects that are easily overlooked, or that even, in many individuals, quite overlap the normal type, seem at least as apt to occur as do the pyrotechnical varieties. Evidence is not lacking that physiological changes, and changes that can only be detected physicochemically, are probably as frequent as changes in visible structures, but geneticists have till now had to have a predominantly morphological training, and anyhow, the morphological is easier to see and deal with. It would be absurd and scholastic to try to classify mutations according to the nature of their effects. A mutation can do practically anything that life can do—or at least a little of it, for life is built out of mutations.

THE RANDOMNESS OF MUTATIONS

The statement just made does not necessarily mean, however, that the average mutation does very much in the furthering of life. The vast majority of observed mutations are positively detrimental, and handicap the individual less or more in the struggle for survival and reproduction. In fact, as Altenburg and I showed in some studies on the fruit fly, *Drosophila,* in 1919, by far the greater number of detectable mutations in it are actually lethal; their effect is to kill the animal before it becomes adult (though of course their effect may be prevented if they are recessive and if the dominant normal gene has been received by the individual from its other parent). Evidence is accumulating that the same situation probably holds true in other forms of life. Now this is just what we should expect, and did expect, on the basis of the theory that a mutation is a chemical change in a gene, occurring at random, as it were, that is, without reference to the effect that would be produced, a-teleologically.

Suppose you prod the works of a watch at random—bring about some alterations in ignorance of the effect it may have? Are you likely to make it a better-running watch? A change, purely accidental in this sense, wrought in any complicated organization, is more likely to injure or wreck than to improve that organization for the specific function (in the case of life, multiplication) which it subserves. But, unless the organization has reached its absolute maximum of efficiency already, there will still remain *some* changes, and therefore *some random* changes, that will help. And so, occasionally, when your watch has stopped or is running poorly, you may knock it, prod it, or drop it, and find that, by the lucky replacement of a cog, or the displacement of a sand grain, it starts up merrily again. We shall return to this topic later. Meanwhile, we stand on our data: Despite the staggering complexity of adaptation in living things, the vast majority of mutations are, as is to be expected, antiadaptive.

It will not suffice, however, simply to call the changes "accidental." An accident is something whose cause was independent of something you are interested in, but every accident has its cause just the same. And so we return again to our perennial question: What is the cause of mutations? Evidently, we may now say, not any outer or inner tendency toward perfection of the life force, but that does not help us very much, scientifically. The mutations whose origination has been known to geneticists have been on the whole very scattered and sporadic, so that little of definite information could be obtained by collecting these observations concerning the conditions which may have been contributary to their occurrence. The trouble was that mutations having a conspicuous visible effect are so very rare anyway that one does not find enough in any one experiment to count. However, the very negativeness of this result, and the varied character of the mutations as they did occur, suggested that their occurrence had little or no relation to the ordinary variables of the environment.

Altenburg and I, in the work previously alluded to, undertook a more systematic test of the possible effectiveness of temperature, by using a technique by which we could count the occurrence of lethal mutations, since we found these arose so much oftener as to be countable. We obtained results indicating, though not proving, that a rise in temperature causes a slight increase in mutation frequency, just as it hastens chemical reactions. Though we now suspect that the difference may really have been due to a slight difference in the amount of radiation occurring in the two groups of cultures, warmer and cooler respectively, later evidence seemed to substantiate it. At best, the result scarcely goes far enough to afford a workable handle for the study of the phenomenon, since the numbers obtained even here are so trifling in response to the great expenditure of technical effort necessary. In addition to this work, efforts have been by no means

lacking, on the part of numerous investigators, to find the cause, or a cause, of visible mutations, by trying all sorts of maltreatments in the attempt to produce such changes. In the course of this work, animals and plants have been drugged, poisoned, intoxicated, etherized, illuminated, kept in darkness, half smothered, painted inside and out, whirled 'round and 'round, shaken violently, vaccinated, mutilated, educated, and treated with everything except affection, from generation to generation. But their genes seemed to remain oblivious, and they could not be distracted into making any obvious mistake in the reproduction of daughter genes just like themselves. The new genes were exact duplicates of the old ones, showing no demonstrable mutations, or at most such a scattering few as might have occurred anyhow.

Either the technique used for finding the mutations was inadequate, or the treatments had little or no effect upon the composition of the genes, or both, and I am inclined to think the latter is correct. And yet mutations certainly do happen, even though rarely. In the examination of over 20,000,000 fruit flies, not specially maltreated, over 400 mutations have been found. These mutations must have causes. What then can the causes be? What subtle conditions are they, apparently so independent even of violent injury and of other drastic and obvious changes in the physiological or pathological state of the organism? In going over the data on mutational occurrences in *Drosophila* the present writer reported in 1920 the finding of evidence that in this fly, when a mutation occurred in a given gene of a cell, not only did the hundreds or thousands of genes of other kinds in that cell remain unchanged, but even the twin gene of the other set in the same cell—i. e., the originally identical gene that the individual had received from its other parent—remained unchanged also. Here, then, are two genes of identical chemical composition, lying very close to one another in the same cell—on the average less than a thousandth of a millimeter apart—and one of them, but not its duplicate, is caused to mutate. Neither do the identical genes in neighboring cells mutate. Evidence for this same kind of occurrence has been adduced in other organisms. Why do not the same conditions, acting on the same materials, produce everywhere the same results? If events in this sphere are apparently so indeterministic, is it any wonder that we could not in our previous trials, by the application of definite conditions, produce definite mutational results?

In view of these accumulating findings, the conclusion seemed to me to become increasingly probable, not that mutations were causeless or expressions of "the natural cussedness of things," or of the devil, but that, as Troland had suggested prior to the finding of this evidence, they were not ordinarily due directly to gross or molar causes, but

must be regarded as the results of ultramicroscopic accidents—events too far removed in fineness to be readily susceptible of any exact control on our part. In other words, an appeal was made to the newly found world of the little which the old-line biologist and philosopher do not always take sufficiently into consideration.

The genes are not only protected by a cell membrane but by a nuclear membrane inside of that, and possibly again by a chromosomal envelope of some kind; they may be well shielded, therefore, from the reach of many poisonous substances and unusual products of metabolism. They can not, however, escape the interplay of the helter-skelter molecular, atomic, and electronic motions that are continually taking place both within and around them, on the part of the substances of which they and their neighbor molecules are naturally composed. Nor can they escape the buffeting action of the electromagnetic stresses and strains occurring through space in the field in which they lie immersed. These various exchanges of energy are not, it is evident, ordinarily consequential enough, or the energy is not directed in sufficiently telling ways, so to distort a gene as to change its composition permanently. Occasionally, however, such a change does occur, and subsequent generations tell the tale.

X RAYS A CAUSE OF MUTATIONS

If this general conception of mutation is valid we must regard it as merely a kind of placing of the problem; we should not yet know just which were ordinarily the critical processes concerned, still less the exact steps involved. The conception carries with it, however, suggestions for further experimental investigation. For among the agents of an ultramicroscopically random character, that can strike willy-nilly through living things, causing drastic atomic changes here and passing everything by unaltered there—not a ten thousandth of a millimeter away, there stand preeminently the X or γ ray and its accomplice, the speeding electron.

There is nothing in protoplasm which can effectually stop the passage of X rays or the related waves of shorter wave length—gamma and cosmic rays. For the most part, in a cell, the rays will pass through; but at isolated, unpredictable spots, depending upon unknown "chance" details of energy configurations, a definite portion, a "quantum" of the rays will be held up, and the energy thus absorbed will issue forth in a hurtling electron, shot out of the atom that stood in the way of the radiation. The atom will be changed thereby, and hence the molecule in which it lies may undergo a change in its chemical composition. But for every atom thus directly changed there are hundreds of other atoms changed indirectly. For the electron, shot out like a bullet (except far faster), tears its path through hundreds of atoms that happen to lie in its way, leaving in its wake a

trail of havoc before it is finally stopped. In this process, many of the atoms through which the electron tears have one or more of their own electrons torn out or dislodged from their proper places; this change in the structure of the atoms often causes them to undergo new chemical unions or disunions that in turn alter the composition of the molecules in which the atoms lay. If a gene is a molecule, then, with properties depending upon its chemical composition, it can be shot and altered by the electrons resulting from the absorption of X rays or rays of shorter wave length. The only question would be, can enough mutations be caused in this way to be detectable by our present methods with doses of rays small enough not to kill or sterilize the treated organism?

With these points in mind, the author undertook in the fall of 1926 a series of experiments designed to test the question at issue. The fruit fly, *Drosophila*, was used since it is so easily and rapidly bred in large numbers and since it rendered possible the employment of special genetic technique for the finding of mutations, that had been elaborated in the course of my previous work on linkage and mutation in this organism. It would take us too far afield here to examine this technique in detail. Stocks of flies had been made up containing in given combinations certain genes with conspicuous effects which would serve to notify the investigator that the chromosome under consideration was present. On making given crosses of these stocks with other stocks various combinations of characteristics would be expected in the first and following generations. If flies with some particular expected combination were, however, absent from a given culture, it would mean that a mutation had occurred that had given rise to a lethal gene—one that had killed the flies containing it before they had a chance to hatch. By noting which combinations were missing, it could be deduced what chromosome of the fly the lethal was in, and at what place in the chromosome it lay. On the other hand, mutant genes having visible instead of lethal effects would be detectable through the appearance of the visible variations, and these too could be traced to their chromosome position through studies of the nature and frequency of the combinations in which they appeared. Mutant genes that were recessive to the normal type, however—and most mutations are recessive—would not have a chance to be seen or found until the second or third generation of offspring subsequent to their origination. The reason why recessive mutations are not evident at once has been explained previously.

In these experiments the adult flies—in some cases the males, in other cases the females—were placed in gelatin capsules and subjected to doses of X rays so strong as to produce partial sterility, though the other functions of the flies are not noticeably disturbed by a dose

several times stronger than used here. The treated flies were then bred to untreated mates, and at the same time numerous control matings of the same genetic type were carried on for comparison, consisting of untreated males crossed by untreated females. Thousands of cultures were used in this and subsequent experiments, in order, if possible, to settle the matter beyond any doubt.

The results in these experiments were startling and unequivocal. To the toiling pilgrim after plodding through the long and weary deserts of changelessness, here indeed was the promised land of mutations. All types of mutations, large and small, ugly and beautiful, burst upon the gaze. Flies with bulging eyes or with flat or dented eyes, flies with white, purple, yellow, or brown eyes, or with no eyes at all; flies with curly hair, with ruffled hair, with parted hair, with fine and with coarse hair, and bald flies; flies with swollen antennæ, or extra antennæ, or legs in place of antennæ; flies with broad wings, with narrow wings, with upturned wings, with downturned wings, with outstreched wings, with truncated wings, with split wings, with spotted wings, with bloated wings, and with virtually no wings at all. Big flies and little ones, dark ones and light ones, active and sluggish ones, fertile and sterile ones, long-lived and short-lived ones. Flies that preferred to stay on the ground, flies that did not care about the light, flies that had a mixture of sex characters, flies that were especially sensitive to warm weather. They were a motley throng. What had happened? The roots of life—the genes—had indeed been struck, and had yielded.

It must not be supposed that all the above types appeared congregated together in one family. The vast majority of the offspring that hatched still appeared quite normal, and it was only by raking through our thousands of cultures that all these types were found. But what a difference from the normal frequency of mutation, which is so painfully low! By checking up with the small numbers of mutants found in the numerous untreated or control cultures, which were bred in parallel, it was found that the heaviest treatment had increased the frequency of mutation about 150 times; that is, an increase of 15,000 per cent.

SIMILARITY OF THE X RAY TO THE NATURAL MUTATIONS

These mutations were obviously of the same general nature as the spontaneous mutations that occur without X-ray treatment. This was shown by the fact that in many cases changes had been produced which were undoubtedly identical with spontaneous variations which had been found in the previous history of the *Drosophila* work; the effects in these cases appeared identical in every particular and the method of inheritance, the position of the gene concerned in the chromosome was found to be the same. In fact, in the chromo-

some which has been subjected to the most intensive study (the X-chromosome) the majority of all the well-known mutations that had previously been found by the dozen or so active investigators in the course of 15 years, now were found to have arisen over again in the cultures of X-rayed flies here. Besides these reappearances there were of course many new types also, more new types than old, but it should be remembered in this connection that new types are continually being found, though with far lesser frequency, in the untreated material also.

The new types of mutations, like the old, conformed in their general expression and mode of inheritance to certain general principles, which I had previously observed to hold in the case of the mutations occurring in untreated material. One of these principles was that the great majority of the mutations of X ray as well as of natural origin are recessive to the normal type, despite the presence of a rather small minority of dominants. Thus the technique of in breeding through a number of generations in order to find the mutations, was found to be justified. It may be remarked here that if human beings are affected by X rays in the same way as flies, we can not expect to find much evidence of a mutational effect of X rays on them from data derived only from the first, or even the first, second, and third human generations, and such a negative result will therefore by no means indicate a lack of significant genetic effect.

The second principle observed was that the X-ray mutations, like the natural ones, included both inconspicuous as well as conspicuous changes, changes of slight or almost impreceptible degree as well as striking changes of structure or quality, and changes that registered their effect, so far as could be determined, only in slight lowerings of the general vitality, as well as those that were more graphically describable. If anything, the more easily overlooked effects were the more frequent.

A third principle noted was that most of the X-ray mutations were in some way detrimental to the animal in living its life—they were steps in the wrong direction in the struggle for existence. This finding has already been discussed in the case of the natural mutations, and it has been explained that this is just what is to be expected, on the whole, of changes that occur at random, accidentally, by "chance"—I care not what term you wish to use to describe the idea that they occur without reference to their consequences, unadaptively, and hence are more likely to be "wrong" than "right" changes, just because there are more wrong roads than right roads to follow, and because, as is well known, the right road is apt to be the narrower. In the case of the X-ray mutations it is easily seen that, if the change occurs as I have pictured it, it *must* occur accidentally, without reference to the possible advantage or disadvantage it would confer,

since the shooting electrons let loose by the X rays are coursing helter-skelter through the cell, quite blindly, and are just as apt to hit one gene as another, to strike it either on its left or its right side, through its heart or its appendix, so to speak, and so will cause one change or another indiscriminately. We have in the X-ray mutations, then, a group of variations which seem *necessarily* to be random, and hence would necessarily be mostly detrimental. In view of this, it is interesting to compare with them in this respect the natural mutations, and to note that, so far as our evidence goes, the natural mutations have, on the average, every bit as much tendency to be detrimental as the X-ray mutations have. The obvious conclusion is that the natural mutations too are random changes, in the same sense that the X-ray mutations are.

As in the studies on natural mutations, so too among our artificial ones, the great majority were lethal—they killed the fly before it ever hatched except where there was a normal gene from the other parent to dominate over the lethal and save the fly's life, so that it could be bred and the transmission of the lethal studied. The changes in wings, eyes, etc., previously mentioned were only the exceptional visible changes, culled from out of a great mass of lethals. Thus, although the great majority of the offspring of X-rayed flies that lived looked normal, many of them carried, hidden by the dominant normal gene, a recessive lethal gene. And if we count up all these lethals we find that the majority of the offspring of heavily X-rayed flies are not really normal in their genes after all, for something over 50 per cent of them contained some kind of lethal mutation that would not work its destruction until a still later generation. This, too, deserves being considered in its bearing on X-ray effects in the case of human beings. Now, previous studies of Altenburg and myself on natural mutations have shown that among them too, although the total frequency of mutations is so much smaller, nevertheless the number of lethals is just as large, relatively to the number of other, visible mutations which occur naturally, as it is among the X-ray mutations. As the lethals differ from the others, after all, merely in being more detrimental, this result simply means again that natural mutations are just as apt to be very detrimental, i. e., lethal, as are X-ray mutations, thus confirming what I have called the "accidental" character of the natural mutations.

The descendants of the X-rayed flies have been bred through many subsequent generations. It has been found that, where a gene was not caused to mutate in the first place, it will not show a subsequent tendency to mutate, without further treatment, i. e., there is no perceptible after-effect on the genes that escaped an immediate hit. On the other hand, those genes that were hit and mutated now breed true to their new type, which in the great majority of cases gives

evidence of being as stable as the original type was before treatment. We now have in the laboratory various mutant races of flies, derived from our earlier X-ray experiments, which have passed through something like 75 or more generations since the time the mutation took place, and there has been no sign in them of any tendency to revert back to the originally normal condition. They have their own, new norm; they are real, new varieties. The new forms are permanent, in so far as the word permanent may be applied legitimately to living things. When crossed to other forms, the new differences obey the same laws of Mendelian and chromosomal inheritance as do the gene differences existing between natural varieties.

THE NATURE AND SIGNIFICANCE OF THE GENETIC EFFECT OF RADIATION

It might perhaps be contended in some quarters that while the artificial mutations may be similar in some respects to natural ones, and even identical with some natural ones, yet they may not be similar to those particular natural mutations which may be termed "progressive"; the mutant genes resulting from which survive, multiply, and thus become a part of the heritage of an evolving species. Such claiments would hold that the X-ray action is necessarily destructive, causing only loss and injury, and that thus it can work only harm, or at least can cause no indefinite amount of progress in organization. Such a contention would rest upon a misconception of the action of the X ray, for it can be shown that the speeding electron is capable of imparting energy to other atoms through which it goes, and that the resulting chemical changes may be of a synthetic character as well as otherwise. However, since we can not analyze chemically the real nature of the changes involved in the production of mutations by X rays, empirical evidence on the question at issue is called for, and that is what we have been trying to obtain.

It is evident, as my wife has suggested, that if the change induced by X ray from, say, a gene designated as large *A*, to a mutant gene of different composition, designated as small *a*, has really involved a destructive process or a loss, then the opposite change, from small *a* to large *A*, must, conversely, involve a constructive process or a gain. With this question in mind, Prof. J. T. Patterson and I have been engaged in some extensive irradiation experiments involving particular characters. The character which we have used most is the recessive mutant character termed "forked bristles" (f) as compared with the dominant normal straight bristles (F). The evidence is now positive and convincing that the X rays not only induce the mutation of straight bristles to the recessive forked, but also the precisely opposite type of change, namely, forked bristles to the dominant straight, and abundant controls have shown that it is really the X

rays which are the inducing agent. Similar but less extensive findings have been made in the case of the mutant character called "scute" and its normal alternative, "nonscute."[2] The mutations arising as a result of X-raying are, therefore, not merely destructive changes, not merely losses. If some are losses, others, then, are gains. Doubtless, as in the case of most chemical reactions, most mutations too are changes involving substitutions and rearrangements, rather than mere losses or gains.

It should be mentioned that, in addition to the changes in individual genes which X rays bring about, they also cause—with considerable frequency, as Altenburg and I have shown—breakages of entire chromosomes or strings of genes, accompanied by reattachments of the broken-off fragments to different chromosomes or to the chromosome-remainder from which they were broken, at a point different from that of before. The rearrangements of genes thus resulting can be analyzed by breeding tests, and at the same time checked up by studies of the chromosomes as seen through the microscope, an undertaking which Dr. Painter and I have been cooperatively engaged upon during the past two years. In this way we have obtained light on the structure and behavior of the genes and chromosomes from a new angle, though space does not permit me to touch upon these results now.[3] There is evidence that such rearrangements of chromosome parts, as well as mutations in individual genes, have occurred during the course of natural evolution.

The question may now be raised, To what extent can all these results be regarded as mere curiosities, effects confined to the mature sperm-cells of the fruit fly, and of little significance elsewhere? In this connection, it may first be pointed out that my results on the fruit fly were promptly confirmed by Weinstein, working at Columbia University, and later by others (Hanson, Patterson, Harris, Oliver) at this laboratory, and more recently by Serebrovsky and his colleagues in Russia and by Doctor and Mrs. Timofeëff-Ressovsky in Berlin. In my own work, the treatments were not confined to sperm cells, but were also applied to the females, and it was found that both the mature eggs and the immature female germ cells (oogonia) were susceptible to the mutation effect. Harris has recently extended the finding to the immature germ cells of the adult male. Patterson has found that the early germ cells of both male and female larvæ

---

[2] Since the above was written, two papers have appeared by Timofeëff-Ressovsky, describing various cases of the induction, by X rays, of mutations in each of two opposite directions.

[3] The production of such changes in chromosome structure by means of X rays has been confirmed by Weinstein and later by Serebrovsky by means of breeding tests on *Drosophila*. By means of cytological analysis, Goodspeed and Olson have found similar effects in tobacco, and so have Blakeslee and his associates in the Jimson weed. The work of the present author and his colleagues, in studying such changes in *Drosophila* by means of breeding tests and cytological analysis combined, has recently been repeated in an elaborate manner by Dobzhansky, with results that are for the most part in striking agreement with those that had been announced by us.

are likewise susceptible, and also the larval somatic cells. The latter finding, which has recently been announced also by Timofeëff-Ressovsky, opens up a whole realm of interesting possibilities in the production of mutant areas of the adult body, derived from cells of the treated embryo—such effects as might result, for instance, in an individual with eyes of different colors, or with parts of the same eye different. Casteel has been making an anatomical analysis of these latter effects through microscopic sections of the eye. The production of mutations by X rays is thus a general effect for *Drosophila*, obtainable in all kinds of cells in that organism. What, now, of the production of the effect on other organisms?

I need not, perhaps, remind the general reader of the fact that all the principles of heredity so far discovered in the fruit fly—the favorite experimental object of many modern geneticists—have proved applicable to animals and plants in general. It is more to the point to mention that investigators elsewhere, working on other organisms, have now reported results of the same kind as those now in question. Thus Stadler, at the University of Missouri, was independently attempting to induce gene mutations in barley and in corn by means of X rays and radium at the same time that I was doing my first experiments along these lines on flies, and he has found indubitable evidence of the production of gene mutations in monocotyledonous plants by both of these means. Following my work on flies, P. W. and A. R. Whiting have obtained positive results by the use of X rays on wasps. Blakeslee, Buchholtz, and the others of this group have a mass of interesting mutation results from X rays and radium applied to the Jimson weed, *Datura*, that extend the findings concerning lethal as well as visible mutations to dicotyledonous plants. With these so widely separated bits of the living world sampled and all responding positively, it is a reckless critic who still would cast a doubt as to the probable generality of the phenomenon.

Radium rays, like X rays, produce mutations, as has been shown by Hanson and by Stadler. This is because they, too, being short wave length high-frequency electromagnetic waves of great energy content, release high-speed electrons, and the cosmic rays, which are still more extreme in these respects, and so release electrons of still higher speed, must necessarily act likewise. For, as Hanson has shown in experiments with radium, the number of mutations produced depends simply on the number of electrons released and the speed and distance they travel (i. e., the total energy of ionization), regardless of the source of the electrons. Oliver too, in experiments with X rays in our laboratory, has obtained evidence that the number of mutations produced is directly proportional to the dosage of radiation used, and Stadler's work points in the same direction. This being true, there being no evidence of a minimal or "threshold" dosage, we are

forced to conclude that the minute amounts of natural radiation present almost everywhere in nature, most of it of terrestrial origin, due to the radium and other radioactive substances on earth (some inside the organism), and a smaller part of it of cosmic origin, apparently derived from the diffuse and distant factories of matter—all this natural radiation must be producing some mutations in the living things on the earth. These mutations must be very scattered and very infrequent in proportion to the total nonmutated population, just because the amount of natural short wave length radiation is very small in any given case, but, considering the extent of the earth and the multiplicity of living things, the total number of mutations so produced per year must be very considerable. It can, therefore, scarcely be denied that in this factor we have found at least one of the natural causes of mutation, and hence of evolution.

How important is this cause relatively? Is it the sole cause of evolution? We do not yet know. Returning to the investigation of the possible effectiveness of poisons and influences other than X rays I have during the past two years tried out a number of drastic treatments, using a refined genetic technique similar to that in the X-ray experiments, which would have allowed of the detection of lethals and other mutations with far greater ease, and therefore in greater abundance, than in the inconclusive experiments of the past. Included among the treatments were heavy doses of manganese and of lead salts, which had been claimed by J. W. H. Harrison (on the basis of what appeared to me genetically unconvincing data) to produce visible mutations in butterflies. There was also included a repetition of the experiments recently reported by Morgan, Sturtevant, and Bridges, who suspected that they had been able to cause visible mutations in red-eyed flies by injuring their eyes with a hot needle, an operation which was followed by a release of the optic pigment and its distribution throughout the body.[4] Our trials of all these and other agencies have given negative results, and it is becoming a question where to stop.

On the other hand, it is true that other conditions, internal and perhaps also external, accompanying the X-ray treatment, may somehow affect the sensitivity of the cells to that treatment. Thus Stadler finds that the sprouting cells of seedlings have mutations produced in them in much greater abundance by a given dose of X rays, than the dormant cells of seeds do, though some mutations are produced in both. On the other hand, both Hanson and Harris, working independently, find that the genes of growing immature germ cells are far less sensitive to the mutating effect of radium or X rays than are the dormant

[4] They announce that they have recently been elaborating upon this work by similar tests on flies with other eye colors, and by artificial injection of substances derived from the eyes. Guyer, who originated these methods in experiments with rabbits, had claimed positive results from them in his material.

genes in mature spermatozoa. I find that the genes in the spermatozoa of the adult male are also more sensitive than those in the germ cells of the female, or than those in the germ cells of the larval male. There seems to be more difference in their sensitivity to the gene-rearranging effect of the rays than in their sensitivity to the transmuting effect on individual genes. The activity of metabolism however, varied by starving, and by feeding and mating the female, had no perceptible influence in my experiments, and, as both Stadler and I have found independently on barley and flies, respectively, extremes of heat or cold applied at the time of treatment have little or no effect.

Thus the work on the physiology of mutation-production is opening up, though as yet in a very empirical stage. And meanwhile, X rays and their relatives remain the only prime cause of mutations yet known. Whether radiation furnishes the exclusive motive power of evolution can eventually be ascertained definitely, through painstaking quantitative determinations of the mutation frequencies existing in the presence of measured minute amounts of radiation. As stated in some previous publications from our laboratory, we have experiments projected which we hope will test this question in flies.

Since, however, mutations in general bear all the earmarks of the X-ray mutations, then, even if not all of them have actually been produced by radiation, it seems legitimate to use the readily obtainable X-ray (radium, etc.) mutations as the handle by which to study them. These X-ray mutations are certainly accidental, being produced by ultramicroscopic events not individually controllable, that take place without reference to the outcome or the advantage for the organism. The natural mutations—*some* of which we know must be due to radiation—are on the average equally as detrimental, and are of the same general nature, so far as their effects are concerned, as the X-ray mutations. Can we then escape the conclusion that they are accidental in the same sense, and that specific mutations are therefore not dictated by any "adaptive reactions" or other specific responses of the organism to climate, or to any other features of its mode of life?

Due, then, to the tremendously magnified effect which each tiny gene can produce, through the processes of growth and development, we have a molar indeterminism, in the origination of genetic variations, resulting from an ultramicroscopic determinism. (We will not quarrel here about whether or not a Heisenbergian "principle of uncertainty" lies beneath the latter in turn.) But now "natural selection" sets to work, weeding out the many disadvantageous mutants here, allowing the multiplication of the few advantageous mutants there, until again from all the maze of variants we have organization returning, advancing, and so, as a statistical consequence, there results a kind of higher molar determinism, finally governing many features of the actual evolution of the species. Thus we are sometimes furnished

with such regular sequences of forms as seen in the gradual modification of the horse's foot, or in the shells of some mollusks, where a knowledge of one part of the series enables us pretty closely to compute the rest.

THE TASK AHEAD

The biologist should, however, not be content to stop with such generalities. The real problems of the generation of new living things are only commencing to open up. The occurrence of the individual variations, although "accidental" in the sense previously explained, nevertheless is subject to a mechanism, our knowledge of which is as yet in its most elementary stage. Moreover, the biologist of broader view realizes that there never has been any one objective in the course of evolution, and that every creature, including man, is only on probation, and may eventually give way before another in which a more advantageous succession of mutations happens to come along. The vast majority of species, in fact, have perished along the way, and only a relatively few survive, through change, to form the continuing thread of life that branches out again.

Man, however, is now the first creature in the world to have this advantage: he has reached some understanding of this process of evolution in which he has hitherto been caught and blown about, and with understanding there frequently comes some measure of control. He can now produce mutations for the first time, and I have no doubt he will soon experiment with this knowledge and in time by its means greatly improve and alter the forms and functionings of those domestic animals and plants which he has taken under his care. Look at the motley shapes of flies that have been made in the laboratory and you will more readily appreciate the possibilities thus presented.

Despite these advantages we are to-day almost as far as ever from producing to order the exact mutations which we want. Enough, for the plants and animals, simply to produce a great many mutations and then take our choice, as nature has done in a far slower and more halting fashion. But the research must go on. Man must eventually take his own fate into his own hands, biologically as well as otherwise, and not be content to remain in his most essential respect, the catspaw of natural forces, to be fashioned, played with, and cast aside. If we have had a billion years of evolution behind us, and we have advanced from something like an amœba to something like a man, then in the many millions of years which are still in store for our world why may we not be able to make a further great advance, perhaps far greater even than this, because under our own increasingly intelligent guidance?

SOCIAL PARASITISM IN BIRDS [1]

By Herbert Friedmann

Curator, Division of Birds, U. S. National Museum

If one were to enumerate the main features characteristic of birds, the chances are that the habit of nest-building would be among the first to be mentioned. This indicates in no uncertain fashion the universality of this habit in this large group of vertebrates, and in turn, this very universality immediately focuses our attention on those relatively few species that neither build nests nor care for their eggs or young. These birds lay their eggs in occupied nests of other species, to whose care they are left, and because of this habit are, for want of a better term, said to be parasitic. The habit is not true parasitism in the real biological sense, and may be called social or breeding parasitism. Few problems in the study of animal behavior have aroused more interest for a longer period of time, and from Aristotle to the present time there is an unbroken series of attempts to explain the origin of this peculiar habit. In the early days of biological science this question was limited to a single species, the well-known European cuckoo, *Cuculus canorus*, and it was of this bird that Aristotle wrote, ending his discourse with the cautious sentence, "People say that they have been eyewitnesses of these things." Since his time a great many individuals have also claimed to have been eyewitnesses of these and similar things, but it is only within the last century that accuracy and precision have been brought into play in these observations and the facts separated from the interpretations. Less than two centuries ago it was found that many cuckoos in Asia were also parasitic, but the habit was still supposed to be confined to the one family of birds.

In the early days of the last century it was discovered that the cuckoos were not the only birds with parasitic breeding habits, and that the cowbird of North America, *Molothrus ater*, a bird belonging to an entirely different order, also exhibited this remarkable mode of reproduction. Later, workers in southern South America found that

[1] Reprinted by permission, with slight omissions, from The Quarterly Review of Biology, Vol. III, No. 4, December, 1928.

some of the neotropical cowbirds were likewise parasitic, and observers in Africa announced that the habit was also found in some of the honey guides. Quite recently a few of the African weaverbirds were shown to be parasitic, and just a few years ago a South American duck, *Heteronetta atricapilla*, was found to possess this habit as well. At present, this manner of reproduction is known to occur in five widely separated and distantly related families of birds—the cuckoos *(Cuculidae)*, the hang nests *(Icteridae)*, to which group the cowbirds belong, the weaverbirds *(Ploceidae)*, the honey guides *(Indicatoridae)*, and the ducks *(Anatidae)*. Of the cuckoos about 70 species are known to be parasitic; of the hangnests, only the cowbirds and the rice grackle, half a dozen species in all; of the weavers, only 3; of the honey guides, all the species of whose breeding habits we have any knowledge, less than half a dozen; and of the ducks, a single species. The entire number of parasitic species forms but a mere handful out of the thousands of kinds of birds known to science.

As the number of birds known to be parasitic increased, interest in the subject increased accordingly, and an enormous literature grew up around the problem. The number of theories brought forth to account for the origin of the habit became almost as great as the number of writers on the subject. Before adding still another to the long list of theories, we may at this point examine the evidence and material available. In order to make the problem more approachable we may limit it for the present to one group of birds—the cowbirds.

THE COWBIRDS

The term cowbirds as used in this paper includes the true cowbirds (genera *Agelaioides*, *Molothrus*, and *Tangavius)* and the rice grackle *(Cassidix)*. The latter is in reality nothing but a large edition of *Tangavius*, although it is not generally called a cowbird. The genus *Agelaioides*, restricted to Argentina, Paraguay, Uruguay, and Brazil, is the oldest and most primitive of the cowbirds. It contains two closely related species, *A. badius* of Argentina, Paraguay, and Uruguay, and *A. fringillarius*, a pale representative form in eastern Brazil. The former is the one that is now well known and will be called the bay-winged cowbird in this paper. The genus *Molothrus* contains the most typical cowbirds—three species with many races—*M. rufo-axillaris* of Argentina, Uruguay, and Paraguay; *M. bonariensis* of South America from Patagonia to Panama; and *M. ater* of North America, from the highlands of central Mexico to the region of Lake Athabaska, and from the Atlantic to the Pacific. *M. rufo-axillaris* will be referred to as the screaming cowbird, *M. bonariensis* as the shiny cowbird, and *M. ater* as the North American cowbird. The genus *Tangavius* contains one species known in life and one known only from four skins preserved in the American Museum of Natural

History in New York and the Museum für Naturkunde in Berlin. The former species is *T. aeneus*, the red-eyed cowbird, the latter is *T. armenti*, Arment's cowbird.

Before taking up the reproductive habits of the different species it is necessary to form a mental picture of their phylogenetic relationships, so that we shall be able to fit the habits into the genealogical tree of the group. There is not space available here to present all the evidence, of which there are several independent lines; a mere diagrammatic outline will have to suffice.

3. *Tangavius—Cassidix.*

1. *A. badius*—2. *M. rufo-axillaris*

3. *M. bonariensis—M. ater.*

This scheme of relationship is supported by geographical (distributional) data, as well as by various lines of biological data such as coloration, song, migration, and courtship display.

BREEDING HABITS OF THE COWBIRDS

The bay-winged cowbird is in every way the most primitive species of the group and probably represents the original condition of the ancestral cowbird stock. It is nonmigratory, and is strictly monogamous. It winters in flocks, and early in spring the individuals leave the flock in pairs. There is no courtship display of any sort. The pairs then wander about looking for old or empty nests, but frequently fight with other birds for possession of occupied nests, usually with the result that the bay wings succeed in ousting the builders and usurp the nests, throwing out any eggs or young that may happen to be present. The birds then breed in these nests, taking care of their eggs and young as do ordinary birds. If no old or occupied nests are available the birds build for themselves and construct very creditable nests, indicating that they still possess the nest-building instinct but bring it into action only as a last resource, when all other means fail them. However, even when (as in most cases) they take over old nests, they do a certain amount of nest building—repairing or adding to the lining, enlarging the entrance in the case of domed nests, rearranging small twigs on the outside, etc. Then, after the nests are renovated or completed, as the case may be, the females lay their eggs, usually five in number, and begin incubating, and rear their young as do most normal nesting kinds of birds.

The screaming cowbird is apparently a direct evolutionary offspring of the bay-winged stock. In the adult stage the plumages of the two species are very different, but the young (juvenal) birds are exactly alike, both having the coloration of the bay-winged cowbird. Like the bay wing, the screaming cowbird is nonmigra-

tory. It is, if anything, even more strictly monogamous, as it is found in pairs all year round, even in the middle of the Argentine winter. So closely are the members of each pair united to each other that it is quite the exception to see a single individual at any time. On a few occasions I have found single birds or groups of three, but in an overwhelming majority of the cases the birds were in twos. Like the bay-winged cowbird, it is a very late breeder, the season for eggs being from December to the end of February for these two species, whereas most small birds in Argentina breed from September to January, and the geographical and ecological ranges of the two species are entirely coincident. The eggs and young of the two are practically identical, but the eggs can be told apart with considerable certainty by one who has studied them intently. The screaming cowbird is, however, parasitic in its breeding habits and confines its parasitic attentions to one species, the bay-winged cowbird.

It is interesting to note, in passing, the ironical aspect of this situation. As far as the available evidence indicates, the main factor coincident with the late breeding of the bay-winged cowbird is the abundance and availability of nests built and since deserted by other species. In other words, there seems to be some correlation between the apparent dislike for nest-building on the part of the bay wing, and its late breeding season. By breeding late it avoids the task of building. The screaming cowbird also is a late breeder but is parasitic, and inasmuch as no other birds are breeding so late in the season, the bay wing automatically becomes the chief, if not the only, victim. In this way additional work devolves upon the species that originally adopted a late laying season to avoid work.

The shiny cowbird is a far more widely ranging species than either of the two already mentioned, and occurs from Patagonia to southern Darien (Panama), while the bay-wing and the screaming cowbirds are found only in the northern part of Argentina, Uruguay, southern Brazil, Paraguay, and Bolivia. It is migratory in the southern part of its range and is less monogamous than either of the other two species found in South America. In general it tends toward monogamy, but in localities where it is very numerous its sexual relations seem unable to maintain themselves unchanged in the face of the pressure of population numbers and the birds become more or less promiscuous, or possibly polyandrous, in their mating habits. This species (and also the screaming cowbird) has a very different type of courtship display and song, differing in this respect from the most primitive species of the group. The shiny cowbird presents a new feature, that of a differential sex ratio, the males being much in excess of the females, while in the first two species the sexes are about equal in numbers. This excess of males almost seems a result of the parasitic habit, as it

allows for a numerical increase of the species without too great an increase in egg-producing individuals. If too many eggs were produced, too few of the natural foster parents would be able to bring up any of their own young and thereby provide an adequate supply of victims for the succeeding seasons. The numerical status of the parasite depends very largely on those of the common host species. The shiny cowbird is an early-breeding species and is parasitic on a great variety of small birds; in fact, almost all the small birds breeding in the range of this cowbird are probably parasitized. Over 100 species have been found caring for its eggs or young.

The North American cowbird is very similar in its habits to the shiny cowbird. In song, courtship display, relative number of the sexes, sexual relations and lack of specificity of host species, the two are very similar. However, the shiny cowbird has the parasitic habit less well developed and wastes large quantities of its eggs, either by laying them on the ground and leaving them there or by laying too many eggs in one nest or in deserted nests, etc. The North American bird is more efficient in the disposition of its eggs, and wastes relatively very few of them. About two hundred species of small birds are known to be parasitized by this cowbird.

The red-eyed cowbird represents another branch of the cowbird tree and is more similar to the screaming cowbird than to any other. It is parasitic on several species, usually birds of genera fairly closely related to itself, such as *Icterus*. The males somewhat outnumber the females, and in general the relations of the sexes are similar to the condition in the North American cowbird.

THE BREEDING AREA

One other topic demands our attention before we can piece together the various bits of evidence offered by the different species of cowbirds. This is the matter of the individual breeding area or territory. Howard (32) has shown that normally each pair of birds establishes an individual breeding area within the confines of which they tolerate no others of their own species. The size of the territory in most cases seems to depend on the abundance and availability of food for the young. As a rule (in by far the greatest number of instances) the males establish the territories and wait there for the arrival of the females. The females then choose the exact site of the nest within the territories of their respective mates. The establishment of the territory is primarily the business of the male, and his main task during the early part of the breeding season seems to be the defense and maintainance of the territory. The territory seems more fundamental than the nest in the complex of instincts of the male.

It follows that the sexual relations of the birds (i. e., monogamy versus promiscuity, etc.) depend largely on their territorial relations,

and inasmuch as these two are intimately bound up with the mode of reproduction, we may profitably examine the territorial situation in the cowbirds.

In the bay-winged cowbird the problem is somewhat simpler than in the others, as each pair has its nest and is thereby tied down to a definite area. However, instead of the usual procedure, we find the reverse is followed. The wintering flocks break up into pairs in the spring, and the pairs of birds go about looking, not for territories, but for nests. They will fight with the builders, if need be, to gain possession of the nest, or else will quietly occupy an uncontested one. Then the territory is extended radially around the nest, instead of the nest site being chosen within the territory as in normal birds.

This altered conception of the breeding territory manifests itself in the defense of that territory. Instead of being the basic thing, the area becomes secondary to the nest and its defense is correspondingly weakened or lessened. This weakening of the defense opens an easy path to a distorted type of sexual relations, such as promiscuity or polyandry.

The territorial situation in the case of the next species, the screaming cowbird, is of interest in that it presents a rather unusual state of affairs, although superficially it seems quite ordinary. This species, as already noted, pairs off early in the season but does not begin to breed until nearly midsummer (January and February). Nevertheless, quite early in the spring it establishes its territories, often as early as the first week in October. Sometimes the period elapsing between the time of territorial establishment and the actual inception of egg-laying amounts to two or even nearly three months. Yet during all this time each pair maintains its particular sphere of influence. Pairs from adjacent territories do not join or mix promiscuously although they do sometimes form temporary groups of four to six birds in neutral feeding areas. Having no nests to care for or young to provide with food, why should these birds establish territories and stay in them day after day, sometimes for nearly a quarter of a year, without making any use of them? One would hardly expect a non-parasitic species endowed with strong, fully developed parental instincts to limit its individual liberty of action for so long a time merely in anticipation of, and preparation for, its reproductive activities. The goldfinch of North America (*Astragalinus tristis*) breeds at the same relative season (reversed) as the screaming cowbird, but the flocks of the former do not break up for pairing and breeding purposes until about a month before egg-laying commences. Furthermore, not only do they have to establish territories and procure mates in this month but also to build nests, which the screaming cowbird never does. The late breeding of the goldfinch is doubtless an adaptation to seasonal food supply but in the screaming cowbird

it seems an old habit phylogenetically derived from the ancestral stock, of which the bay-winged species is the surviving member. Food supply can not explain why the bay-wing and the present species breed so late in the season, as the food of the young of both these birds is the same as that of the young shiny cowbird, which is an early-breeding bird. However, the bay-wing breeds late because it habitually breeds in old nests of woodhewers (*Anumbius* and *Synallaxis*) and ovenbirds (*Furnarius*). Late in the season there are plenty of these nests available, while earlier they are fewer in number, most are occupied by the builders, and the cowbirds would have to fight for them. The greater ease and certainty with which these nests could be obtained later in the season probably was largely responsible for the postponement of the breeding season in the bay-winged cowbird. The present bird, the screaming cowbird, shows in several ways that it is an offshoot from the bay-wing stock, and its habit of breeding very late is doubtless due to a similar tardiness of reproductive season in the stock from which it evolved.

DESERTION OF BREEDING TERRITORIES

The late breeding coupled with fairly early establishment of "territories" which remain unused for a considerable length of time has brought about a very interesting condition in the screaming cowbird, namely, not infrequent desertion of territories before egg laying commences, with the subsequent establishment of new territories later as the reproductive urge becomes more imminent. In this connection the following observations, taken from my book, are of interest.

In Concepción district, Tucumán, Argentina, I watched several pairs of screaming cowbirds whose territories were more or less adjacent. As the season wore on I found that one pair forsook its territory and disappeared. The male of this pair was identifiable by an extreme harshness in his notes. He and his mate were well nigh inseparable. I never saw either bird alone or more than a couple of feet away from the other, even when feeding on neutral ground. The desertion of this territory took place between the 22d and 24th of November. On December 2 I was surprised to find the same male securely established in a new territory about a mile away. With him constantly was a female, just as before. Whether or not it was the same female I could not say, but of the identity of the male I had no doubt. The old territory of this male was occupied by a new pair of birds four days after it was deserted by the first pair. From this it would hardly seem possible that the "fitness" of this territory had in some way been lessened to the extent of causing the original pair of tenants to desert it. It was possible that the

female of the original pair had died and the male had deserted on that account. In order to test this I shot the females of three pairs on three near-by, and, to me, well-known territories. In none of these cases did the males desert; they remained and soon found other mates. I can attribute this desertion to no cause other than the diminishing potency of the territorial instinct with the passing of time between the establishment and the utilization of the territory in question. Another bit of evidence in this connection was gathered at the height of the breeding season of the species (January) at Santa Elena in Entre Rios, eastern Argentina. I was studying a bay-winged cowbird's nest, making daily notes of everything concerned with it. On January 8, 1924, I noted that a pair of screaming cowbirds flew into the tree in which the nest was and stayed around in the near-by branches but were kept away from the nest by the bay wings. Suddenly another pair of screaming cowbirds flew into the tree and joined the first pair. A minute later the second pair (the newly arrived birds) flew over to the nest and were chased back by the bay-wings. They flew back to the first pair and a little while later both pairs flew off together, screaming as they flew. It seemed that in this case one of the two pairs of screaming cowbirds was encroaching on a nest in the territory of the other. The birds being strictly monogamous, only one pair would occur in any one territory, and the other pair must have just recently come in. Screaming cowbirds were not very plentiful in that district, and there was plenty of land available for the other pair to use. There were also plenty of bay wings scattered over the country. This looked as though the second pair had not yet established themselves in a breeding territory although it was very late in the season. It is hardly possible that this pair had not attempted to do so before; it seems likely that they were birds that had deserted a territory and were not yet settled in a new one.

POPULATION PRESSURE AS A MODIFIER OF BREEDING HABITS

In the case of the shiny cowbird, the numercial abundance of the species usually modifies or hides the true state of affairs. The sexual and territorial relations of this species are easily overridden by the pressure of population, resulting in undue competition for breeding areas. In this species the factors influencing the extent of the individual territories are not associated directly with the food supply, but with the abundance of nests in which to deposit the eggs. The denser the small-bird population, the smaller the territory of each cowbird. Where the cowbirds are very abundant the territories as such become almost impossible of definition and demarkation. The results of a protracted study of this species indicate the following iacts. In areas where the birds are not extremely abundant, they

pair off regularly and each pair has its own territory. In places where the cowbird population is great, the birds still pair off, but inasmuch as they make no pretense of protecting the territory other individuals filter in, remain there a day or so and then pass on. Consequently it is more usual to see several of these birds together (with the males predominating in number) than to see them in groups of twos. The following observations, taken from my book (23), will illustrate this point. I watched a certain pair of shiny cowbirds, whose territory I knew, every day for several weeks. The female laid the first egg in a nest of a Chingolo song sparrow (*Brachyspiza capensis*) on October 25.

I was surprised, however, to find that another female cowbird also laid in this nest on the same date. It looked as though the male was constant in its territorial relations but that females came and went promiscuously. However, in the next few days I found that the same female had laid an egg in each of four chingolo nests in this territory, including nest No. 1. The eggs were laid at intervals of one day, but at the same time, each day I kept finding eggs of other female cowbirds in nests where they certainly were not the day before. Thus in nest 1 no less than four different female cowbirds deposited one egg each, two of them removing (or apparently removing) one of the eggs already in the nest. In nest No. 2, eggs were deposited by two different cowbirds; nest No. 3 contained eggs of two different cowbirds; nest No. 4 contained only 1 cowbird egg. All in all I judged, by the size, color, marking, and texture of the eggs as well as by the date of deposition that no less than six different females had deposited eggs in nests within the limits of this particular territory. However, the important point is that one bird, which I shall call the real mate of the male whose territory is under discussion, laid an egg in each of the four nests, or four eggs in all, while of the other five females using these nests, four laid but one egg apiece and the other laid two. Furthermore the two eggs laid by the last bird were laid four days apart. This means either that this particular female wandered about from one territory to another or else that it laid during the interval in nests in this territory which I never found.

Nevertheless, in spite of all this confusing data the total evidence leads me to believe that the shiny cowbird is chiefly monogamous and each mated female sticks to one territory but that both the sexual and territorial relations are so weak as to be very easily modified or sometimes even destroyed by conditions, particularly by the unnatural, increased density of cowbird population per given area around cultivated districts. Of course this frequently results in what seems to be sexual promiscuity and does destroy, in great measure, the "territory," in the sense that that particular area is no longer the domain of only one female but has become the happy hunting grounds of all that may care to make use of it. The same is largely true for the North American species, *Molothrus ater*.

One more point needs to be discussed here. The males outnumber the females to the same extent as they do in *M. ater* of North America—about 3 males to every 2 females. Assuming that every breeding female has a mate and but one mate, there would be still one-third of the males without mates and consequently without any means of satisfying their sexual desires. If several males having no "territories" or "spheres of influence" joined in the pursuit of the same female, disaster to the race would undoubtedly ensue. But each male (except in the case of the yearling birds that begin breeding very late) has his own territory and there he awaits the coming of a mate. The greater the number of cowbirds to a given

area, the greater is the competition for territories with the result that the territories are smaller than elsewhere where the cowbirds are fewer. The smaller each territory the less assurance a female has of a requisite number of nests in which to lay, and so what probably happens is this: After utilizing all the available nests in the territory of any one male she passes on to that of the next. If that territory is already occupied by a female, the newcomer finds the available nest supply inadequate and passes on still further afield. Often she may leave an egg or even two in a certain territory before passing on. Inasmuch as there are at least 50 per cent more males than females, it means that after each female has exhausted the "territory" of her particular male she still has half as much more coming to her in other places. This arrangement not only gives all the females a fairly equal chance to lay the maximum number of eggs but it also brings about a state of affairs wherein each male can find satisfaction in the appeasement of its sexual desire. However, this state of affairs can hardly be called polyandry for, although in the course of a season each female may have several mates, she has only one at a time and only one in a territory. Most monogamous birds change mates with each brood and yet no one would call the females polyandrous, the males polygamous, or the species promiscuous. In the cowbirds, if the birds were originally more than one brooded, the broods have been merged in adaptation to the parasitic habit. One would be more justified in calling the males polygamous as they have intercourse with some of the wandering females while still mated themselves. Yet the male does not leave his territory to collect a harem but takes what comes his way, and not having any concept of parental instinct can hardly be accused of polygamy. There is a great difference between this and a nonparasitic species wherein the male has a paternal interest in two nests simultaneously.

In fact if the females did not wander further afield after exhausting the possibilities of the territories of their respective mates, at least one-third of the males would not be able to appease their sexual desires without forsaking their territories and intruding into those of other males. The loyalty of each male to his territory is not to be thought of as "virtuous" in any way [For the biology of "virtue" see any of the pseudo-scientific sentimental nature writers], but is due to the fact that he would have nothing to gain by wandering.

So then, it seems that the shiny cowbird is monogamous, under normal conditions, but where artificial conditions have caused a great, unnatural increase of the species, the inherent instinct is not strong enough to stand unmodified against the increased competition, and frequently is modified so extensively as to belie its original status.

The sexual and territorial relations in the North American cowbird are practically the same as in the preceding species, except that they are usually less violently modified, as the birds are not so crowded. In a general way this is also true of the red-eyed cowbird, but in the latter species the numbers are usually low enough so that the birds have sufficiently large territories to avoid competition, and monogamy is more easily observed. It is only fair to say that less is known of the habits of this species than of any of the others, but for our purposes it is relatively unimportant, as it is off the main line of cowbird descent.

HOW DID THE PARASITIC HABIT COME ABOUT?

Before utilizing the above data in the formulation of an explanatory theory it may be well to present and comment on the leading current

hypotheses. The first to be considered is that the source of the parasitic habit is to be sought in the polyandrous condition which all parasitic birds were supposed to exhibit. Pycraft (40) and Fulton (24) are among the best known exponents of this view. While it is possible (though not probable) that some parasitic cuckoos may be polyandrous, the cowbirds are certainly more or less monogamous, and such promiscuity as occurs is more likely to be a result than a cause of the parasitic habit. *Vidua macroura*, a parasitic African weaverbird is also monogamous, and Chance (13) writes of the European cuckoo that "* * * whether cuckoos are polygamous, polyandrous, or promiscuous is a very open question. I am inclined to the belief that they are, at least often, promiscuous. I should not, however, lightly dismiss the theory that some pair as normal birds * * *." Fulton admits that the question of polyandry and parasitism is all in a circle and that it is hard to say which came first. He inclines to the view that polyandry causes parasitism. In the cowbirds the circle is still open and there can be no question that parasitism is not caused by polyandry.

The best theory advanced as yet, and one which my studies tend to support in part, at least, is that of Prof. F. H. Herrick. This writer studied the cyclical instincts of birds and found that not infrequently the cycle is interrupted by various causes which result in a general lack of harmony between its successive parts. He suggested that the parasitic habit may have originated from a lack of attunement of the egg-laying and the nest-building instincts which resulted in the eggs being ready for disposition before a nest was ready for them. His theory was based largely on a study of the black-billed cuckoo, *Coccyzus erythrophthalmus*, and a comparison of its life history with that of the European cuckoo, *Cuculus canorus*, which, of course, is parasitic, while the former is not.

He found that of all the perturbations which are apt to arise at almost any step in the cyclical sequence of instincts the commonest was a failure in the "adjustment of nest building to the time of egg laying," and it was at this point that he suggested the parasitic habit took its rise.

"The door is thus opened wide to parasitism in its initial stage, whenever the acceleration of egg laying or the retardation of the building instinct becomes common, with or without irregularity in the egg-laying intervals." He applied this idea to both the cuckoos and the cowbirds and probably would have extended it to cover the parasitic weavers and honey-guides as well had he known of them at the time. He writes that "Parasitism could never succeed as a general practice on a large scale, and the fact that it is a specialty of two families of birds shows that it is probably correlated with a peculiarity which they possess in common. This is to be found in a

change in the rhythms of the reproductive activities, leading to a change of instincts * * *. As to the 'why of this problem' that is, why has the normal rhythm of the reproductive cycle been disturbed * * * nothing is certainly known * * *." (Herrick, 30).

The first writer to see that one explanation would not serve for all the different groups of parasitic birds was G. M. Allen. In the chapter on parasitic birds in his admirable book (1) he discusses all the parasitic groups in a general way and ends by saying that one must be prepared to find that the parasitic habit has been acquired in more than one way, and independently in the different groups exhibiting this habit. Wisely refraining from offering an explanation of parasitism, he suggests several "possible ways of origin." One of the possibilities is that parasitism may have arisen from the occasional laying of eggs in strange nests by birds that are very sensitive to the ovarian stimulus provided by the sight of a nest with eggs resembling their own. This is substantiated by experimental evidence collected by Craig, who found that in doves ovulation could be induced by comparable stimuli. In the case of the flicker [*Colaptes auratus*] " * * * the presence of a nest egg seems to encourage them to keep on laying as if to attain a number whose contact stimulus would satisfy the brooding instinct. It may be that in the case of those ducks whose eggs seem so often to be laid promiscuously in nests of their neighbors, the mere sight of a nest with eggs resembling their own may act as a stimulus inducing them to add to the number" (1). Chance's field observations on the European cuckoo are more or less in accord with this idea as he believes that the sight of her victims building their nests acts as a stimulus to ovulation so that the female parasite has an egg ready to be laid five or six days later. This is also true of some of the cowbirds.

However, I can not agree with this suggestion as a possible origin of the parasitic habit unless it be accompanied or preceded by a marked reduction in the attachment of the bird to its own nest. Even if the sight of eggs in strange nests stimulated egg production in a bird that was not parasitic, its natural instincts would associate the resulting eggs with its own nest and the bird would probably lay them there, unless, as I said above, its attachment to its nest were greatly diminished. Then, too, after it has laid the proper number of eggs, "whose contact stimulus would satisfy" its brooding instinct, it would normally begin to incubate and stop laying. If its nest attachment were subnormal in strength, the bird might then wander about to some extent and, on receiving more visual stimuli might revert to egg-laying. However in such a case, its own eggs would have a lessened chance of survival.

Another possibility suggested is that if a bird got into the habit of breeding in old nests of other birds, it would be easy

> * * * to imagine that the bird might not discriminate between a newly completed nest and one recently abandoned. The result would be that if the intruder laid in the new nest, its rightful owners would resent the intrusion and prevent the repetition of the act, even though they had themselves to bring up the unwelcome addition. It is likely, too, that the greater abundance of new than of deserted nests would favor the frequency of such mistakes until the parasitic habit would have become established.

This suggestion seems well founded and possesses the virtue of being simple. However, even in this case, the actual origin of the parasitic habit is not explained. A possible method of evolution of the parasitic habit is suggested but no indication is given as to why the birds, if repulsed at a new nest, do not continue nest hunting until they find an unoccupied one. Furthermore, birds that breed in old nests of other species do not normally lay the first egg on the same day that they first occupy the nest, but usually the possession of a nest seems to provide the stimulus necessary for egg production. From this it follows that if a bird of such breeding habits did try to occupy a new nest it would either be repulsed by the owners before it had a chance to lay, or by the time it did lay an egg, the owners would have forsaken the nest, leaving the new occupant to care for its eggs, just as if it had originally gone to an old nest to breed.

In order to explain the origin of the parasitic habit we must first decide whether it is the result of a change from a normal nesting habit or whether it is a phylogenetically original one. All the evidence derived from a study not only of the cowbirds, but of birds in general, points unmistakably to the conclusion that parasitism is an acquired habit and not an original one. It is inconceivable to think of a long line of parasitic birds having no origin in normal nesting types. Again, for the evidence behind this statement I must refer the reader to my book (23) as space does not permit of its inclusion here. It seems entirely safe and justifiable, then, to assume that parasitism was not the original condition in the cowbird stock. The problem, then, is not whether the cowbirds were or were not always parasitic, but how they lost their original habits and acquired their present ones.

LOSS OF PROTECTING INSTINCTS AS A FACTOR IN THE ORIGIN OF PARASITISM

To quote again from my book:

> We have seen that all five species of cowbirds establish breeding territories and that the distinctness or the definiteness of the territory is most pronounced in the most primitive, nonparasitic, bay wing, while it is least definite, and at times, almost imaginary, in the shiny cowbird and the North American *Molothrus*. In the bay wing, and its offshoot, the screaming cowbird, the birds are practically always strictly monogamous and only one pair is to be found in a given territory.

In the other two species, where the parasitic habits are better developed, the territories are distinct chiefly in districts where the species are not abnormally numerous; but where they are unnaturally abundant, the territorial instincts are not strong enough to stand unmodified against the pressure of cowbird population. Distinctness of terrritory depends on the amount of what may be called "territorial protection" displayed by the male. In most birds the male establishes a breeding territory and protects it from the inroads of other males of its own species. The female sometimes has this instinct as well. In the parasitic cowbirds we see that the birds have still retained the territorial desire but have lost most of the instinct to protect their breeding areas. The original factor involved in this loss is the reversal of the usual method of territorial acquisition in the most primitive of the cowbirds. We have seen that birds, usually the males, establish their territories, and then choose a nesting site somewhere within that territory. The bay-winged cowbirds, however, reverse this process. They leave the winter flocks in pairs and, instead of staking out their "claims" they look for old or even new nests in which to breed. They fight for these nests if necessary, and when once in occupation, they extend the territory radially around the nest. In this way the territory, instead of being the primary consideration, becomes a matter of only secondary importance and with this reduction of its significance, the instinct to defend it is correspondingly lessened. In this way the amount of "territorial protection" displayed by the male is decreased and in the more recent, parasitic species, where the protecting instincts are further reduced, the territory of any one male is very apt to be invaded by other males of its own species.

Furthermore, in the bay-winged cowbird, we have seen that the female has lost most of her protecting instinct and seems to spend most of what she has before laying her eggs, after which the eggs are largely dependent on the male for protection. The female is always quite bold and fearless when away from the nest, but very shy and nervous when incubating. Apparently she has the instinct to conceal her eggs in a nest, usually not of her own building, but has very little desire to protect them once they are laid. If not for the protection of the male (and very fearless he is), she would probably be unable to care for her eggs, and if the male should lose his protecting instinct the result would be that the female would have the instinct to lay (or conceal) her eggs in nests but not to care for them (or protect them). This would open an easy path to parasitism. If we reexamine the habits and instincts of other cowbirds we find that this is exactly what has happened. The males have lost their protecting instincts and we find that the loss is more complete in *M. ater* and *M. bonariensis* than in *M. rufo-axillaris*. The very fact that we still find these somewhat obscure, but yet real, stages in the loss of the protecting instincts, only serves to emphasize the downward path these instincts have taken. So then, it may be said that the immediate cause of the origin of the parasitic habit in the cowbirds was the loss of the protecting instinct of the male. The fact that the female, still earlier in the history of the group, lost most of her protecting instincts can not be called a causitive factor because as long as the male retained his instincts of defense, as in the bay-winged cowbird to-day, the birds were not parasitic. What caused the almost complete loss of these instincts in the male we can not definitely say, but the factor which started the weakening, and finally brought about their destruction was the reversal of the territorial and nesting habits. When the territory became of only secondary importance the impulse to protect it was correspondingly weakened. At the risk of seeming paradoxical it might almost be said that the fact that the ancestral cowbirds cared more about the nest than the territory had much to do with the origin of the parasitic habit. The complex of reproductive instincts became unbalanced and eventually collapsed. In other words, the birds were more interested in a secondary than a primary consideration with the result that the former suffered much more than the latter

Fortunately we have a clue to the way in which the male lost his protecting instinct. In order to fully appreciate its significance it is necessary to digress for a moment and consider the evolution of the screaming cowbird from the bay-wing stock. As already indicated in a previous section the screaming cowbird is obviously a direct offshoot of the stock of which the bay-winged cowbird is the living example. The range of the screaming cowbird is wholly contained within that of the bay wing and in general the habitat or type of country occupied by the two species is the same. I always found both species in the same type of environment. It seems then that there could have been no geographical or ecological isolation in this case to preserve and differentiate the budding form which in its present state we call the screaming cowbird. Consequently the isolation necessary to preserve the distinctness of the newly arisen species must have been physiological. The physiological isolation was probably that of differential breeding seasons. Probably the original *rufo-axillaris* was an early breeding bird (*badius* is a later breeder). Although *rufo-axillaris* to-day is a late breeder, the facts that its courtship season comes early in the spring, and that it establishes its territories very early, point to the conclusion that it once was an early breeding bird as *bonariensis* and *ater* are to-day. Inasmuch as the bay wing is nonparasitic and inasmuch as the screaming cowbird is a direct offshoot of this stock, it seems probable that originally the latter species was also nonparasitic. In other words, the change between the normal and the parasitic mode of reproduction occurred within the racial history of *M. rufo-axillaris*. Assuming that in most ways the original habits of the screaming cowbird were similar to those of the bay wing, we should expect that the birds tried to breed in nests of ovenbirds, wood hewers, etc., but tried to do so early in the season. As elsewhere indicated, the struggle for nests is much greater early in the season than later on, and the screaming cowbird, handicapped hereditarily by a weakened territorial instinct, probably could not succeed in this struggle. We have seen that sometimes screaming cowbirds establish territories in the spring, occupy them for considerable periods, and then desert them without ever having utilized them. This indicates very strongly that the weakened territorial instinct of the male is often insufficient to maintain its influence long enough to "make connections" with the somewhat more vernal development of the egg-laying instincts of the female. In this lack of attunement between the territorial instincts of the male and the egg-laying instincts of the female the parasitic habit probably had its origin. This lack of attunement seems to have been caused by the diminution of the protecting territorial instincts of the male and this diminution seems in turn to have been started by the reversal of the territorial and nest-building instincts in the stock from which the screaming cowbird evolved.

So much, then, for the cowbirds. In the other groups of parasitic birds, other factors seem to have been instrumental in bringing about the parasitic breeding habit. Too little is definitely known of their biology to attempt an explanation, but probably the habit arose differently in each of the five families containing parasitic species.

HOST SPECIFICITY IN THE CUCKOOS

In the cuckoos, we have one clue which indicates that territory had little to do with the inception of parasitism. This is furnished by the peculiar feature of host specificity shown by some of the species, especially in Europe and Asia, but to a lesser extent in Africa and Australia as well. In the classic case of the European cuckoo, *Cuculus canorus canorus*, it is now well established that generally each

female deposits all her eggs in nests of a single species. That is, one cuckoo may parasitize only meadow pipits, another may lay its eggs only in nests of hedge sparrows, while still another may victimize reed warblers exclusively. Each individual has its own particular species of victim to which it generally limits its attention. The species *Cuculus canorus canorus* lays its eggs in the nests of a great number of different kinds of birds, but each individual tends to use the nest of but one kind. The parasitic habit in *Cuculus canorus canorus* may therefore be said to be characterized by *individual* host specificity. In the Indo-Malayan region there are a great many genera and species of parasitic cuckoos, some of which have carried this specificity to an extreme with the result that the great majority if not all, of the eggs are laid in nests of a single species or group of allied species. Thus the Indian koel, *Eudynamis honorata*, lays its eggs wholly in nests of crows and jays. In British India it victimizes the Indian crow, *Corvus splendens*, and the jungle crow, *Corvus macrorhynchus;* in Burma it foists its eggs upon the Burmese crow, *Corvus insolens*, and the Burmese jay, *Pica sericea;* in southern China the victim is the starling, *Graculipica nigricollis*. In large districts in its range practically all the individual koels victimize the same species of bird. In other words, within each of these districts the individual host specificity of each individual koel is the same as that of every other one, and taking into consideration the entire range of the species the number of host species is so small and the species so closely related that the individual host specificities of all the koels are very similar. The parasitic habit in *Eudynamis honorata* may therefore be said to be characterized by *specific* host specificity.

The development of specific from individual host specificity may readily be accounted for by natural selection operating under conditions which would tend to emphasize the value of small differences. Thus, in the case of *Eudynamis honorata* the bird (and its egg) is too large to be successful with small fosterers. The crows are everywhere common and their nests open and plainly visible and the birds (and their eggs) fairly close in size to the koels. An abundant, accessible group of species being everywhere available, the individual koels having crows as their individually specific hosts would rapidly increase and gradually eliminate their less successful fellows that depended on more precarious and more uncertain specific hosts. In time the entire membership of the species *Eudynamis honorata* would be composed of individuals parasitic on crows.

During the course of my field work in Africa I found that the various parasitic cuckoos were ecologically isolated from each other to a very considerable extent, i. e., one species lived in dense forest, another in open country, and among species of different genera living in the same type of country, one species restricted its parasitism to open,

arboreal nests, while others laid only in domed nests either in low trees, or on the ground. The ecological factors affecting the ranges and habitats of the various parasitic cuckoos necessarily limit the number of host species available to each species of cuckoo. In the tropics the number of species and of individual birds is very large and the resulting struggle for existence more intense than in the more lenient regions to the north and south. As a result of the keeness of the competition we find that similarity in habits survives side by side where those habits do not affect the same species. That is, a habit such as the parasitic one could survive far more easily in many species in the same region if they did not conflict with each other than if all were parasitic on the same group of host species. So then, in the bushveldt of Africa we find that the little golden cuckoos, *Lampromorpha*, victimize weaver birds, grass warblers, and a few other types of birds, chiefly limiting their attention to the weavers and *Cisticolas*. Most (almost all) of their victims build domed or covered nests, some of them on the ground. In the same districts we find that the crested cuckoos, *Clamator*, confine their visitations to open, arboreal nests such as the golden cuckoos never molest. However, with a fair number of species to choose from there is no environmental reason why a certain individual parasite should further limit its range of activities by tending toward extreme host specificity. It is not of any particular obvious benefit to the parasite to be still further restricted in this way.

The only way to arrive at a proper understanding of the way in which host specificities might have begun is to study individual birds as well as species. In working on the reproductive habits of birds one of the first things to be determined is the extent and definiteness of the individual breeding territories. Chance and others have done this for the European cuckoo, *Cuculus canorus canorus*, with splendid results. In the case of the African species of parasitic cuckoos I found that all of them establish definite breeding territories to which they adhere during the egg-laying season. The males of some species, such as *Lampromorpha caprius*, *Chrysococcyx cupreus*, and *Cuculus solitarius*, are very faithful to their territories. The breeding territory in the case of a parasitic bird is based not upon a sufficiency of food for the young but upon an adequacy of nests for the eggs. As stated above the small golden cuckoos parasitize weaver birds (*Ploceus*, *Hyphantornis*, *Otyphantes*, etc.) very frequently. A great many species of these weavers are arboreal and build their nests in large colonies, often as many as a hundred or more nests in a single tree. I found that in several cases a pair of didric cuckoos, *Lampromorpha caprius*, had established their territories around trees containing colonies of weavers and in at least four cases the territories were entirely restricted to single trees. These weaver colonies very seldom

contain more than a single species of weaver, at least in my experience. In such cases the individual cuckoos, by restricting their territories to single trees, automatically limit their parasitism to single species. These weaver colonies are very common all over the African continent south of the Sahara and the didric cuckoos are also common and widespread. Therefore it seems very likely that individual host specificities are being formed in many individual cuckoos in the way just mentioned.

It is impossible to imagine any cuckoo as originally going around the countryside, inspecting various kinds of nests, making notes of the dietetics of the different species, and then repairing to its favorite perch to cogitate upon its researches and finally decide to limit itself to any one of them. Specificities must have originated without premeditation and survived because they were convenient. The fact that not all parasitic cuckoos are specific indicates that some never went through any such experience as the didric cuckoo is subject to. Host specificity is decidedly convenient to a didric cuckoo fortunate enough to have within its territory a whole colony of suitable nests. Their territorial instincts of defense, like those of most parasitic species, are faulty and if they had to wander far afield in their search for nests the chances are they would not be able to keep any territory for themselves. That is what seems to have taken place in the Indian koel, *Eudynamis honorata.* In this species individual territories as such seem nonexistent any more. Baker (5) writes that the koel, "* * * sets all cuckoo laws in defiance; many birds breed in the same area and even in the same tree; and as many as 11 have been taken together."

The important point in all this for our immediate purpose is that the development of host specificities seems to depend on the strict adherence to individual breeding areas. This indicates that with the development of the parasitic habit in the cuckoos there was no coincidental diminution of the reality of the territory such as we find in the cowbirds.

The evolution of the habit in different groups of birds in widely separated parts of the world is one of the most notable examples of parallel development in the great group of birds.

LIST OF LITERATURE

(1) Allen, Glover M. 1925. Birds and their attributes. Pp. 198–216.

(2) Audubon, John James. 1842. Birds of America, Vol. 4, pp. 18–22.

(3) Baker, E. C. Stuart. 1907. The oölogy of Indian parasitic cuckoos, pts. 1, 2, 3. Journ. Bombay Nat. Hist. Soc., Vol. 17, pp. 72–83, 351–374, 678–696.

(4) ———. 1913. The evolution of adaptation in parasitic cuckoos' eggs. Ibis, 10th series, Vol. 1, No. 3, pp. 384–398.

(5) Baker, E. C. 1922. Cuckoos; some theories about the birds and their eggs. Bull. Brit. Orn. Club, cclxvii, Vol. 42, pp. 93–112.

(6) ———. 1923. Cuckoos' eggs and evolution. Proc. Zool. Soc. Lond., Vol. 19, pp. 277–295.

(7) Baldamus, E. 1853. Neue Beiträge zur Fortpflanzungsgeschichte des europaischen Kuckuks. Naumania, Vol. 3, p. 307.

(8) Barrett, C. L. 1906. The origin and development of the parasitical habits in Cuculidae. Emu, Vol. 6, pp. 55–60.

(9) Barrows, W. B. 1883. Birds of the lower Uruguay. Bull. Nut. Orn. Club, Vol. 8, pp. 133–134.

(10) Bendire, Charles E. 1893. The cowbirds. Rep. U. S. Nat. Mus., pp. 587–624.

(11) Chance, Edgar P. 1916. Observations on the cuckoo. Brit. Birds, Vol. 12, No. 8, pp. 182–184.

(12) ———. 1919. Observations on the cuckoo. Brit. Birds, Vol. 13, No. 4, pp. 90–95.

(13) ———. 1922. The Cuckoo's secret.

(14) Coues, Elliott. 1874. Birds of the Northwest: A handbook of the ornithology of the region drained by the Missouri River and its tributaries. Dept. of the Interior, U. S. Geol. Surv. Terr. Misc. Publ. No. 3, pp. 164, 180–186.

(15) Craig, W. 1913. The stimulus and the inhibition of ovulation in birds and mammals. Journ. Animal Behavior, Vol. 3, No. 3, pp. 215–221.

(16) Evans, A. H. 1922. Notes on the life history of *Cuculus canorus*, with exhibition of eggs. Proc. Zool. Soc. Lond., Vol. pt. i, pp. 197–199.

(17) Friedmann, Herbert. 1925. Notes on the birds observed in the lower Rio Grande Valley of Texas during May, 1924. Auk, Vol. 42, No. 4, pp. 537–554.

(18) ———. 1927. Testicular asymmetry and sex ratio in birds. Biol. Bull., Vol. 52, No. 3, pp. 197–207.

(19) ———. 1927. Notes on some Argentine birds. Bull. Mus. Comp. Zool., Vol. 68, No. 4, pp. 220–227.

(20) ———. 1927. A revision of the classification of the cowbirds. Auk, Vol. 44, No. 4, pp. 495–507.

(21) ———. 1927. A case of apparently adaptive acceleration of embryonic growth rate in birds. Biol. Bull., Vol. 53, No. 5, pp. 343–345.

(22) ———. 1928. The origin of host specificity in the parasitic habit in the Cuculidae. Auk, Vol. 45, No. 1, pp. 33–38.

(23) ———. 1929. The Cowbirds: A study in the biology of social parasitism. C. C. Thomas Co., Springfield, Ill.

(24) Fulton, Robert. 1903. The kohoperoa or koekoea, long-tailed cuckoo, (*Urodynamis taitensis*): An account of its habits, etc., etc. Trans. New Zealand Inst., Vol. 36, pp. 113–148.

(25) Gloger, C. W. L. 1854. Das geschlechtliche Erhaltniss bei den nicht selbst brutenden Vögeln. Journ. f. Ornith., Vol. 2, pp. 137–143.

(26) Grinnell, Joseph. 1909. A new cowbird of the genus *Molothrus*, with a note on the probable genetic relationship of the North American forms. Univ. Calif. Pub. Zool., Vol. 5, pp. 275–281.

(27) Herrick, Francis Hobart. 1907. Analysis of cyclical instincts of birds. Science, Vol. 25, p. 725.

(28) ———. 1907. The blending and overlap of instincts. Science, Vol. 25, p. 781.

29) ———. 1910. Instinct and intelligence in birds. Pop. Sci. Monthly, pp. 532–558, 82–97, 122–141

(30) HERRICK, FRANCIS HOBART. 1910. Life and behavior of the cuckoo. Journ. Exp. Zool., Vol. 9, pp. 171–233.

(31) ———. 1911. Nests and nest-building in birds. Journ. Animal Behavior, Vol. 1, pp. 159–162, 244–277, 336–373.

(32) HOWARD, H. ELIOT. 1920. Territory in bird life.

(33) HUDSON, WILLIAM HENRY. 1920. Birds of La Plata, Vol. 1, pp. 69–115.

(34) JOURDAIN, F. C. R. 1925. A study of parasitism in the cuckoo. Proc. Zool. Soc. London, pp. 639–667.

(35) LEVERKÜHN, PAUL. 1891. Fremde Eier im Nest, Ein Beitrag zur Biologie der Vögel. pp. 1–4.

(36) LOEB, JACQUES. 1918. Forced movements, tropisms, and animal conduct. Chap. 18, pp. 156–164.

(37) MEIKELJOHN, R. F. 1917. Some reflections on the breeding habits of the cuckoo (*Cuculus canorus*). Ibis, 10th series, Vol. 5, pp. 186–223.

(38) MILLER, LEO. 1917. Field notes on Molothrus. Bull. Am. Mus. Nat. Hist., 1917, pp. 579–592.

(39) PEARL, RAYMOND. 1914. Studies on the physiology of reproduction in the domestic fowl. VII. Data regarding the brooding instinct in its relation to egg production. Journ. Animal Behavior, Vol. 4, pp. 266–289.

(40) PYCRAFT, W. P. 1910. A history of birds, pp. 127–134.

(41) RIDGWAY, ROBERT. 1902. The birds of North and Middle America, pt. 2. Bull 50, U. S. Nat. Mus., pp. 202–212.

(42) ROBERTS, AUSTIN. 1913. Egg-collecting in the Bushveld. Journ. S. Af. Orn. Union, Vol. 9, pp. 34–37.

(43) ———. 1917. Parasitism amongst finches. Annals Transvaal Mus., Vol. 5, pt. 4. pp. 259–262.

(44) STERNBERG, CHRYSANTHUS. 1869. Zur Fort-pflanzungsgeschichte des Viehstaares *Molothrus sericeus*. Journ. f. Ornith., Vol. 17, pp. 125–136.

(45) SWYNNERTON, C. F. M. 1918. Rejections by birds of eggs unlike their own with remarks on some of the cuckoo problems. Ibis, 10th series, Vol. 6, pp. 127–154.

(46) THOMSON, J. ARTHUR. 1923. The biology of birds, pp. 309–310.

(47) WALLACE, ALFRED RUSSEL. 1868. A theory of bird's nests. Journ. of Travel and Nat. Hist., p. 73.

(48) WATSON, JOHN B. 1909. The behavior of noddy and sooty terns. Pub. 103 Carnegie Inst. of Washington, p. 223.

(49) WETMORE, ALEXANDER. 1926. Observations on the birds of Argentina, Paraguay, Uruguay, and Chile. Bull. 133, U. S. Nat. Mus., pp. 383–388.

(50) WILSON, ALEXANDER. 1810. American Ornithology Vol. 2, pp. 145–150.

HOW INSECTS FLY

By R. E. Snodgrass

Bureau of Entomology, United States Department of Agriculture

A particular interest attaches to the study of the wings of insects, because, in some respects, they act more after the manner of human inventions for aerial locomotion than do the wings of any other flying creature. Though man has never been successful in equipping himself with wings, and has largely given up the hope of acquiring them, he has succeeded in making machines that will fly; and, whether his craft is lighter than air or heavier than air, its driving mechanism is a set of rotating blades, the nearest counterparts of which in the animal world are the rapidly whirring wings of certain insects.

It is impossible, however, to draw any close comparison between the structure of man-made machines and that of animal mechanisms. There are fundamental principles of physics, or of mechanics, or, rather there are fundamental truths of nature, which physicists have discovered and mechanics make use of, that give the possibility of locomotion both to animals and to machines; but the means by which these principles have been employed may differ widely. Man's chief idea for producing motion, by other means than his own or another creature's muscles, is to make something turn around. The windmill, the water wheel, the engine wheel, the propeller, all depend for their effect on continuous rotary movement of one part on another. The animal, by the very nature of its structure, is debarred from the use of separate elements in its motor devices, the parts of its body are continuous and can be merely flexible on one another; at best, therefore, they can attain only a partial rotary movement. The source of intrinsic movement in animals is always a contractile tissue, in most cases a muscle. But a muscle pulls in only one direction; it does not expand except as it is opposed by some other force acting in the opposite direction. Hence, muscles usually occur in antagonistic pairs. In insects, however, the counteraction against muscle contraction is often produced by elasticity in the skeletal element to which the muscle is attached. The mechanical principle employed in nearly all animal mechanisms, therefore, is that of the lever without other elaborations. Hydraulics, however, plays an important part in the movements of the alimentary canal, and in the locomotion of soft-bodied animals.

The wings of insects are organs *sui generis*, which is to say, there is nothing else exactly like them. In fact, it may be claimed that insects are the only animals that possess true wings. The wings of a bird, or the wings of a bat are merely the fore legs of the animal made over for purposes of flying; the flying fishes glide through the air on their pectoral fins, but these organs also are the fore limbs, which were modified primarily for swimming; the flying mammals are equipped with folds of skin along the sides of the body, which enable them to extend their leaps from one tree to another, but such dermal expansions are parachutes rather than organs of true flight.

I. THE ORIGIN OF INSECT WINGS

Insects are among the oldest of all animals that have living representatives on the earth to-day. Their earliest fossil remains that have been found occur in the rocks of the geologic period commonly known as the Carboniferous, which, according to present methods of calculating past time, may have been laid down as long ago as 300,000,000 years. Mammals, birds, and flowering plants did not then exist, and such reptiles and amphibians as were contemporaneous with the Carboniferous insects were quite different creatures from their modern relatives. Vegetation, however, was abundant, and there were forests of tall trees, though both the trees and the plants of the undergrowth had more the appearance of ferns than of any of our modern kinds of plants, except the few species directly descended from Carboniferous ancestors. The Carboniferous forests flourished principally in swampy districts and around the edges of lagoons, where, as a result of the subsidence of the land, masses of sodden débris and fallen tree trunks accumulated through long ages, and have produced most of our present deposits of coal.

The conditions of the Carboniferous swamp forests were favorable to two classes of insects, namely, insects adapted to living in the forests themselves, and others adapted to unhindered flight over open stretches of water. A review of the known Carboniferous insects shows that these two types actually predominated, or almost exclusively made up the insect fauna of the forests and swamps of that time. The insects of the first class consisted principally of roaches (fig. 1); those of the second class comprise dragon flies, May fly like insects, and insects of an extinct group known as the Paleodictyoptera (fig. 2 A). It is very doubtful, however, that the insects known from the Carboniferous rocks represent anything like the variety of insect forms that existed at the time these rocks were laid down, for there were large areas of open country on both continents where many species may have flourished whose remains have not been preserved.

The remarkable thing about the Carboniferous insects is not that they existed in great abundance at so remote a period, but that they differed comparatively little from modern insects. Of course, ento-

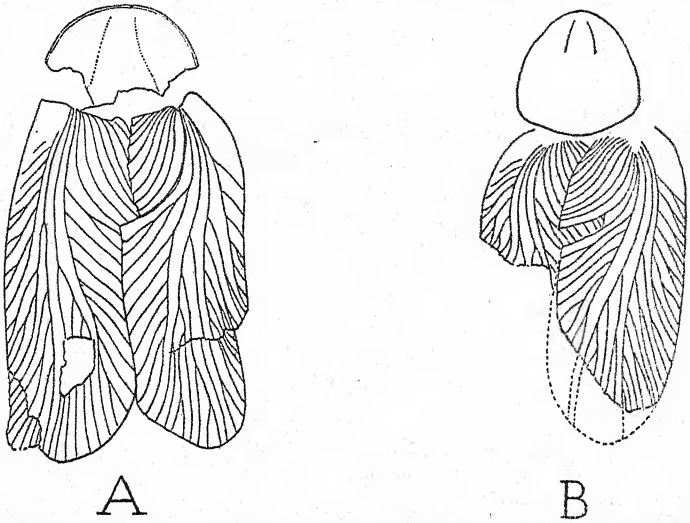


FIGURE 1.—Carboniferous roaches. A, *Asemoblatta mazona* (from Handlirsch after Scudder); B, *Phylloblatta carbonaria* (from Handlirsch)

mologists find many characters that separate the Paleodictyoptera and their associates from their modern relatives, but the distinctive features have to do mostly with details of the wing venation. All the

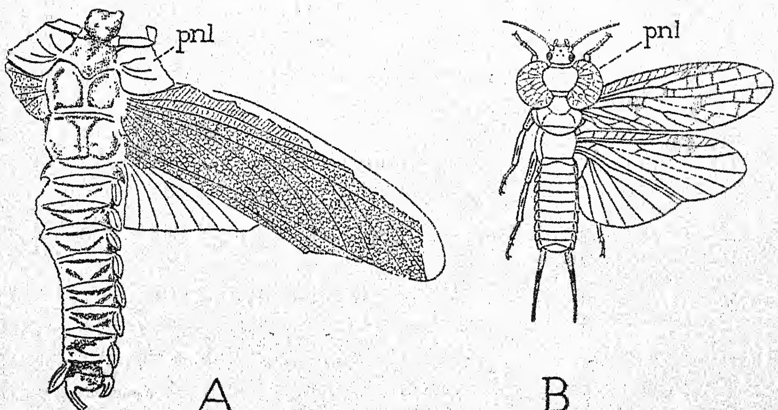


FIGURE 2.—Paleozoic insects with paranotal lobes (*pnl*) on the prothorax. A, *Stenodictya lobata*, one of the Paleodictyoptera (from Brongniart); B, *Lemmatophora typica*, a primitive stone fly (from Tillyard)

Carboniferous insects so far discovered had two pairs of well-developed wings, the structure of which is so nearly like that of the wings of present-day insects that only a specialist would discover the dif-

ferences. In bodily form and structure there was nothing to distinguish a Carboniferous insect from one of its modern descendants; the oldest species known had a head, a thorax, and an abdomen, with four wings and six legs carried by the thorax.

One important conclusion, therefore, that we must draw from a study of the Carboniferous insects is that they do not by any means represent the primitive ancestors of insects. Having already fully developed wings, the Carboniferous insects themselves must have been evolved during millions of years preceding their time from wingless forms of which we have no record. Any attempt to explain the genesis of insect wings, then, must be purely conjectural, but we may arrive at a fairly satisfactory conclusion concerning their origin by a study of the wings themselves and the thoracic segments that support them. In one feature, however, some of the ancient insects do give us a slight clew to the possible nature of the primitive wings, as we shall see presently.

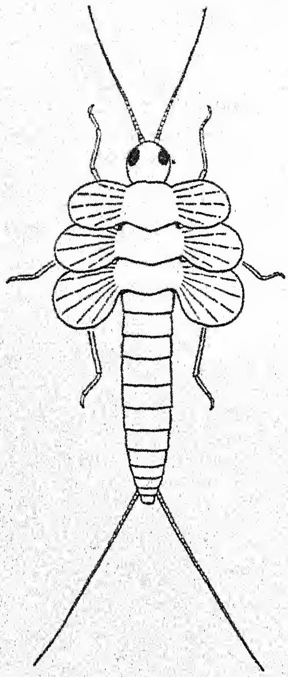


FIGURE 3.—A suggestion of the possible structure of a primitive insect provided with three pairs of glider lobes, or lateral extensions of the back plates of the thoracic segments

The wings of all modern insects are carried by the second and third segments of the thorax. Structurally they are flat outgrowths of the lateral edges of the back plates of these segments. In their development they begin as flat pads or pouchlike outgrowths of the body wall, the two layers of which eventually come together and form the upper and lower surfaces of the mature wing. Semitubular thickenings of the opposed surfaces give rise to the veins. The canals of the veins represent, therefore, the remnants of the original wing cavity, and they contain the tracheæ, nerves, and blood of the wings.

Among the Carboniferous insects there are frequently found species which have a pair of small, flat lobes resembling the developing wing pads, which extend laterally from the margins of the *first* segment of the thorax, or prothorax. (Fig. 2 A, B, *pnl.*) These prothoracic lobes suggest, therefore, that the wings have been evolved from similar lobes on the mesothorax and metathorax. There is no evidence to suggest the improbable view that insects ever had three pairs of fully developed wings used for flight; but we may assume that three pairs of flaps, or paranotal lobes as they have been termed, forming a series of overlapping plates on each side of the thorax (fig. 3),

could have served some important function. The idea that comes most easily to the imagination is that the fanlike extensions of the body wall constituted a glider apparatus, enabling its possessor to sail downward from elevated positions, or perhaps from one elevation to another, as do the modern flying squirrels with their parachute-like folds of skin stretched between the legs on the sides of the body.

Something of the possibilities of a sailing or gliding insect may be demonstrated with a model cut from a piece of thin cardboard according to the pattern of Figure 4, and given a proper ballast by attaching a weight beneath. When passively released from any altitude the cardboard model drops straight down; when given a forward impulse, however, it can be made to sail downward with a graceful forward glide extending a distance varying with the height from which it is projected. The ballast is most important; it may be a crumpled piece of sheet lead held on with a pin or thread, but it must have just a certain weight, determined by clipping it down to the most effective size, and it must be attached beneath a point near the center of the thorax.

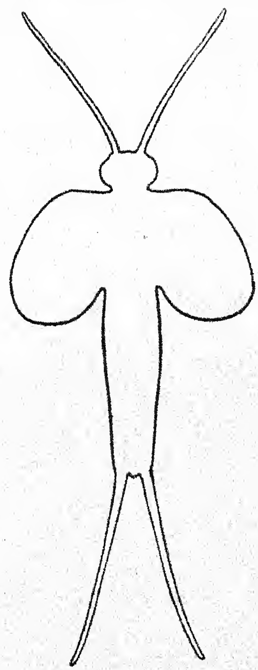


FIGURE 4.—Outline of a mode that can be made, when properly ballasted, to show something of the possibilities of a glider insect

From the performance of this model we may conclude that two conditions are essential to make gliding possible, aside from the possession of a glider apparatus. The first condition demands that the center of gravity be in the region of the body supporting the glider lobes; the second, that the creature must have the ability to project itself into the air. We would draw the inference, therefore, that insects equipped with glider lobes, if the lobes were confined to the thorax, had slender abdomens and carried the weight of their viscera more evenly distributed in the body than do many of the more specialized insects of the present time, and furthermore, that the gliding insects had well-developed legs which enabled them to run swiftly off the end of a support, or to launch themselves into the air by a vigorous leap. Many of the modern grasshoppers do not depart far from this primitive mode of flight, except in that they combine an excellent pair of saltatorial legs with a pair of expansive sails that can perform also, in a weak manner, as organs of true flight.

The question always arises, or is deliberately brought up to embarrass every speculation in evolution, as to how organs could have been

evolved in their earlier stages when they were too small to serve any specific function; and if we can not answer this question it is taken to invalidate the assumption implied by the theory. Certainly, paranotal lobes on the thorax could not have had any locomotory function until they were large enough to serve as gliders. And yet, many modern insects have lateral extensions of the back plate of the prothorax, such as occur frequently in the beetles, which appear to be of no particular use to their possessors, and in some species of mantids the back plate of the prothorax is expanded into a large, flat shield. (Fig. 5.) Utility probably guides the course of an organ's evolution, but it does not necessarily determine its inception. Specific structures may develop for no practical reason at all. Some writers have supposed that the paranotal lobes of insects served first as gills for breathing in the water but this theory must assume that insects had an aquatic stage in their phylogeny, of which there is no evidence.

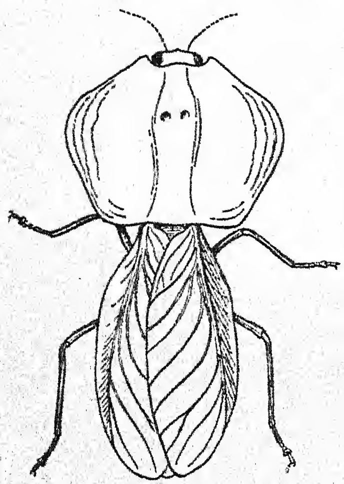


FIGURE 5.—A mantis from Ecuador with large lateral extensions of the back plate of the prothorax

There are existing to-day certain small insects, known as the Apterygota because they not only lack wings but they contain no evidence in their body structure of being descended from winged ancestors. They are apparently direct descendants of the unknown, primitive, wingless progenitors of all the insects. Indirectly the Apterygota furnish evidence of the evolution of wings in the winged insects, or Pterygota, from paranotal lobes. The Pterygota are characterized by a special type of structure in the plates forming the lateral, or pleural, walls of the thoracic segments, the pleural structure being essentially the same in the wingless prothorax as in the two wing-bearing segments. In the Apterygota the corresponding plates are quite different from those of the winged insects, and differ much in the several apterygote families. We must conclude, therefore, that the peculiar structure of the pleural walls of the thoracic segments in the Pterygota, and their basic uniformity in the three segments of the thorax means that the walls of these segments once served a common purpose. This purpose evidently was the support of a pair of paranotal lobes on each thoracic segment. (Fig. 6.) The lack of pleural plates in the lateral walls of the abdominal segments similar to those of the thorax suggests that paranotal lobes of the abdomen, if present, never reached a size of functional importance.

II. STRUCTURE OF THE WINGS

It is a long way from immovable paranotal lobes to fully developed wings capable of sustained flight. In the first step toward the status of wings, the paranotal lobes of insects had simultaneously to become flexible at their bases and to acquire a motor mechanism that would impart to them the movements necessary in organs of flight. Flight, it must be observed, is not to be accomplished by a mere up-and-down flapping of a pair of flat appendages; as will be explained later, in order to generate forward motion, wings must be capable not only of movements in a vertical direction, but also of some degree of anterior and posterior movement accompanied by a partial rotation on their long axes. The mechanism of an insect's wings, therefore, must be such as to produce at least the movements necessary for progression in the air. Insects that fly most efficiently, however, have evolved an apparatus capable also of controlled flight, of sidewise flight, of rearward flight, and of hovering. Finally, to this equipment most insects have added a special mechanism for folding the wings horizontally over the body when not in use.

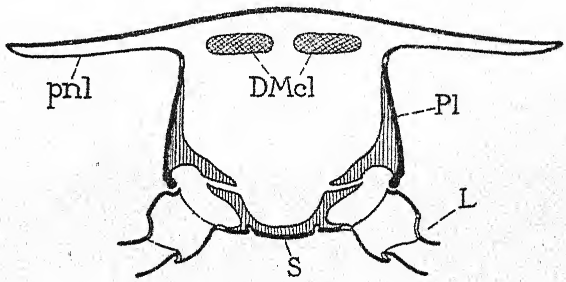


FIGURE 6.—Theoretical, diagrammatic cross section through a thoracic segment of a hypothetical insect with paranotal, or glider, lobes in place of wings. *DMcl*, Dorsal longitudinal, intersegmental muscles; *L*, base of leg; *Pl*, pleuron; *pnl*, paranotal lobe; *S*, sternum

Winged insects may be divided into those that keep the wings extended straight out at the sides when at rest, or which merely close them vertically over the back, and those that fold the wings horizontally over the body. Among modern insects, the first group is represented by the dragon flies (figs. 7, 8) and the May flies (fig. 9); the second includes most of the other insects. In the Paleozoic era, the insects that did not fold the wings included the dragon flies and May flies of that time, and also the members of the Paleodictyoptera, so far as can be judged from their fossil remains. These insects were inhabitants of the open, watery spaces, and probably used their legs principally for perching; they had no occasion for crawling about in places where spread wings would be an encumbrance to their movements. Their general habits were evidently similar to those of the modern May flies and dragon flies, and in their younger stages they probably lived in the water as do at present the members of these two groups of insects. The ancient insects that folded their wings horizontally over the back when not in use included the roaches and

various forms that appear to be representative of several other modern orders of wing-folding insects. The roaches at least were inhabitants of the forests, adapted to living in the matted vegetational débris of the forest floor, on the scaly-barked trees, or between the bases of their frondlike leaves.

The dragon flies belong to the order Odonata, but there are two distinct suborders of them. One suborder, known as the Anisoptera, includes the ordinary large species, or true dragon flies (fig. 7), which, when at rest, keep the wings spread straight out at the sides of the body. The other suborder is the Zygoptera and includes species generally smaller in size which, when at rest, fold the wings over the back with

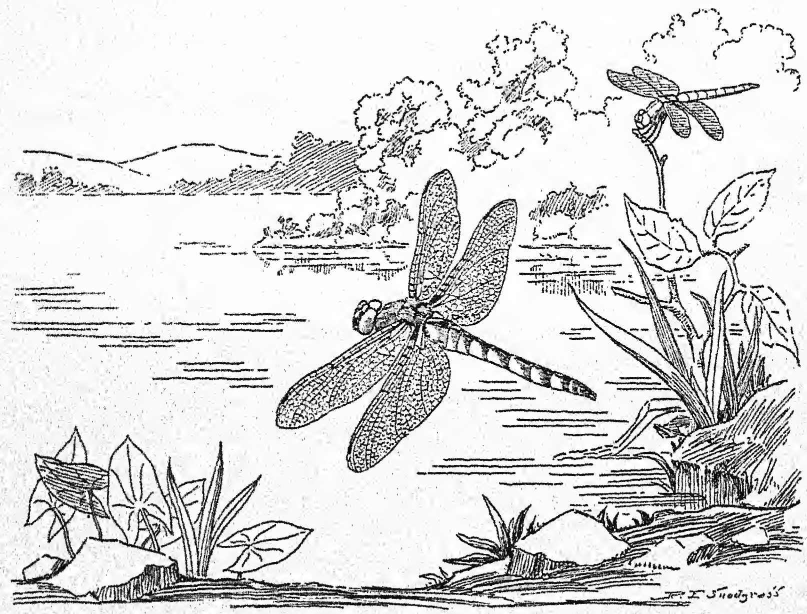


FIGURE 7.—Dragon flies of the suborder Anisoptera. When the insects are perched the wings are held horizontally at right angles to the body

the dorsal surfaces together. (Fig. 8.) Members of the Zygoptera are sometimes distinguished as damsel flies; most of them are rather weak creatures with long, slim abdomens and slender wings narrowed at the bases. They are comparatively feeble fliers and are easily caught. The true dragon flies of the suborder Anisoptera are subdivided into two families, the Libellulidae and the Aeschnidae. The libellulids are the common dragon flies seen about streams and pools, where they perch on the ends of twigs from which they dart out on vigorous short flights in pursuit of some small passing insect. The aeschnids include those large species that we used to call Devil's darning needles. They are most efficient fliers, being seldom seen to alight anywhere as they go skimming above the surface of the water,

and they often make long excursions inland, appearing in places where a dragon fly is least expected. So agile are they on the wing that the collector must sometimes resort to the gun and bird shot to procure specimens of them.

The May flies are members of the order Ephemerida. They are mostly fragile, short-lived creatures in the adult stage, and when at rest fold the wings straight up over the back with the dorsal surfaces together. (Fig. 9.)

All other modern winged insects, with a few exceptions such as the butterflies, fold the wings posteriorly and horizontally over the body when they are not in use. This manner of folding the wings may be distinguished as flexion. It is quite different from the other, in which the extended wings are merely brought together vertically over the back, and it involves the presence of a special mechanism of flexion which the dragon flies and May flies do not possess.

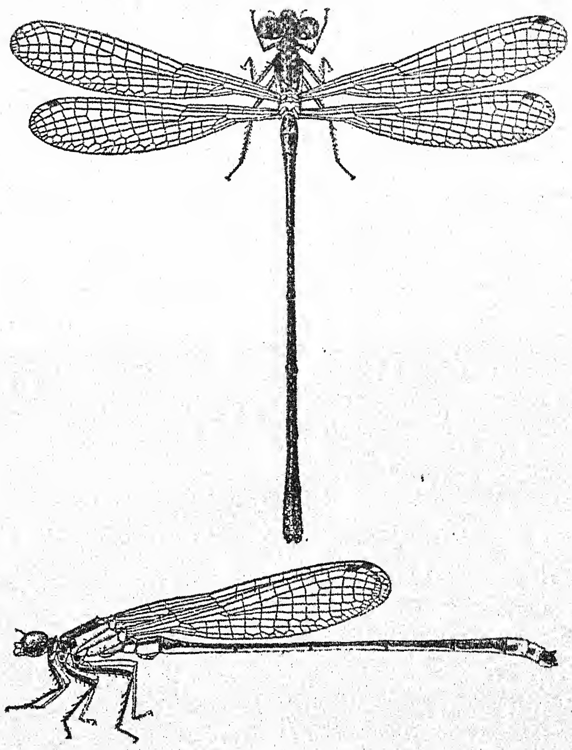


FIGURE 8.—Dragon flies of the suborder Zygoptera, called damsel flies, which, when at rest, fold the wings in a vertical plane over the back (*Ischnura cervula*, from Kennedy)

Since the wing-flexor apparatus has very evidently been added to that which produces the movements of flight, it is usually supposed that the insects which do not flex the wings are descendants of a more primitive group of ancestral insects than are those which flex the wings. The fundamental structure of the wings we might suspect, therefore, would be best preserved in the wings of the dragon flies and May flies; but it is certain that these insects, though of relatively primitive origin, have developed many specialized characters of their own. Particularly is this true of the dragon flies. The structure of a "generalized" wing, then, is to be judged rather from the *ensemble* of the wing characters in all insects than from a study of the wings of any particular group of insects.

The general wing mechanism, including the muscles that generate and regulate the wing movements, will be described in following sections. To understand how the motor elements give the essential movements of flight to the wings, it will be necessary first to know something of the structure of the wings themselves and the details of their connections with the body. The principal features of the wings are the veins, the articulation to the body, the flexor apparatus, and the differentiation of the wing area into special regions in insects that flex the wings.

The wing veins.—The wings of adult insects are thin, membranous extensions of the body wall strengthened by the riblike thickenings known as veins. (Fig. 10.) The principal veins of each wing spring from the wing base and branch in varying degrees in the distal parts of the wing. The work of many entomologists has shown that, underlying the great diversity of vein pattern in the numerous groups of insects, there is evidently one fundamental plan of wing venation. All winged insects, therefore, would appear to be derived from one primitive stock that evolved the paranotal lobes into movable organs of flight.

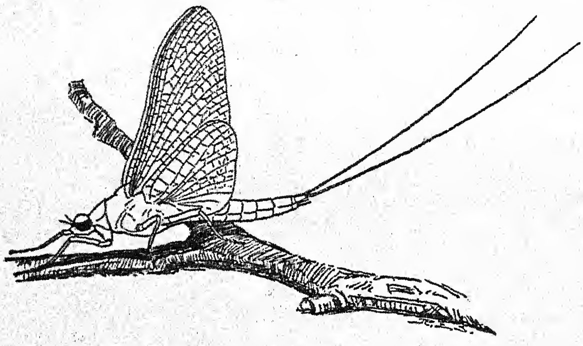


FIGURE 9.—A May fly, a member of the order Ephemerida. When at rest the wings are folded vertically over the back

The system of naming the principal veins now commonly adopted, with a few alterations, by nearly all entomologists is that worked out by Comstock and Needham, shown diagrammatically in Figure 10 A. The first vein is the *costa* (*C*); it usually forms the anterior margin of the wing, but sometimes it is submarginal. The second vein is the *subcosta* (*Sc*), typically forked into two short branches. The third vein is the *radius* (*R*), usually the strongest vein of the wing; distally it forks near the middle of the wing, and the posterior prong (*Rs*) breaks up into four branches. The fourth vein is the *media* (*M*), forked dichotomously into four principal branches. The fifth vein is the *cubitus* (*Cu*), with two branches. The rest of the wing veins, according to the Comstock-Needham system of vein nomenclature, are the *anal veins*, distinguished as the *first anal* (*1A*), *second anal* (*2A*), etc.

There are certain objections to including all the veins posterior to the cubitus under the one term "anal." In the first place, the so-called first anal is found to be in some cases a basal branch of the cub-

itus, and for this reason Tillyard (1919) has renamed it the second branch of the cubitus, and Karny (1925) terms it the cubital sector. In other insects, however, the same vein apparently has no basal connections in the adult wing, and the writer (1929), for convenience, has called it the *second cubitus*. (Fig. 10 B, *2Cu*.) In any case, this vein has no relationship with the other so-called anal veins; the latter

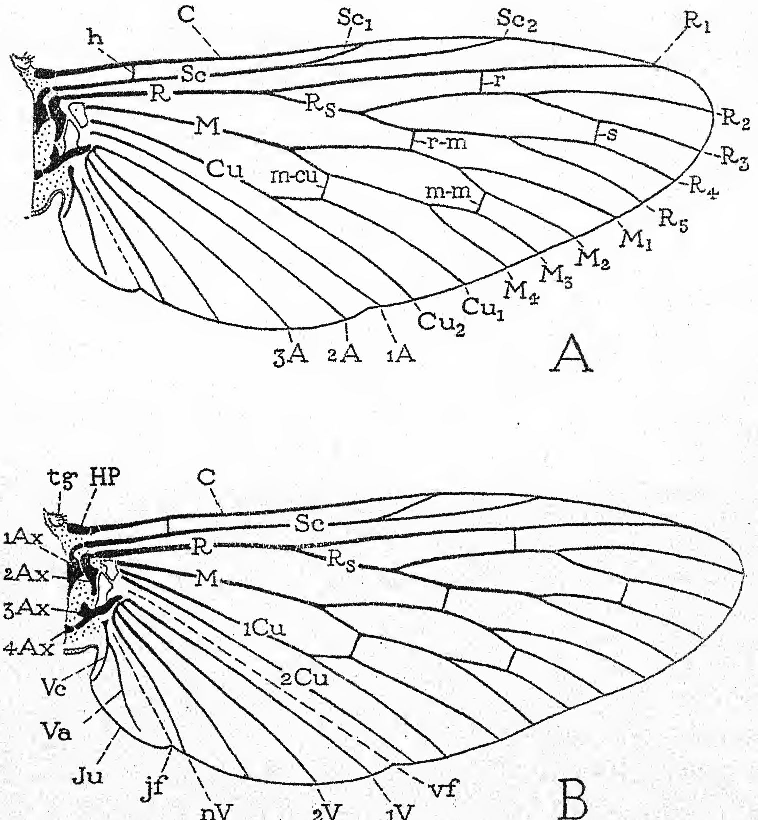


FIGURE 10.—The veins and articular sclerites of the wing of an insect that folds the wings horizontally over the back. A, Diagram of a wing with the veins named according to the Comstock-Needham system; *1A*, *2A*, first and second anal veins; *C*, costa; *Cu*, cubitus; Cu_1, Cu_2, branches of cubitus; *h*, humeral cross vein; *M*, media; M_1–M_4, branches of media; *m–cu*, medio-cubital cross vein; *m–m*, median cross vein; *R*, radius; R_s, radial sector; R_1–R_5, branches of radius; *r*, radial cross vein; *Sc*, subcosta; Sc_1–Sc_2, branches of subcosta. B, Nomenclature of the veins and articular sclerites used in this paper; *1Ax*, *2Ax*, *3Ax*, *4Ax*, first, second, third, and fourth axillary sclerites; *1Cu*, first cubitus (*Cu* of A); *2Cu*, second cubitus (*1A* of A); *HP*, humeral plate; *jf*, jugal fold, plica jugalis; *Ju*, jugal region; *1V*, first vannal vein (*2A* of A); *2V–nV*, second to last vannal veins; *tg*, rudiment of tegula; *Va*, vena arcuata; *Vc*, vena cardinalis; *vf*, vannal fold, plica vannalis

(fig. 10 A, *2A*, *3A*, etc.) constitute a natural group of veins in the posterior part of the wing associated with the third articular sclerite of the wing base (B, *3Ax*). Since the wing area supported by these veins is often expanded into a large, fanlike region, the writer (1929) has suggested calling the veins of this region the *vannal veins* (Latin

vannus, a fan), distinguishing them individually as the *first vannal* (fig. 10 B, *1V*), *second vannal* (*2V*), etc.

The innermost part of the wing proximal to the region of the vannal veins is often differentiated as a lobe or a distinct part of the wing designated by Martynov (1925) the *jugal region* because in the fore wing it sometimes bears a small lobe, or jugum, serving to yoke the fore and hind wings together. In this region there is sometimes a network of irregular veins, but again the jugal region may contain one or two quite definite veins, named the *vena arcuata* (fig. 10 B, *Va*) and *vena cardinalis* (*Vc*) by Martynov.

The area of the wing containing the veins may be thus divided, especially in the wing-flexing insects, into three regions. The first is the prevannal region, or remigium, the second is the vannal region, the third the jugal region. (Fig. 14.) The remigium and the vannus are often separated by a vannal fold, or *plica vannalis* (fig. 10 B, *vf*), while the vannal and jugal regions are separated by a jugal fold, or *plica jugalis* (*jf*). The vannal fold, however, is sometimes doubly plicate, and a secondary vein, the *vena dividens* (fig. 15 B, *Vd*), then lies between the two lines of plication. This concept of the structure of the posterior part of the wing will at least serve for purposes of description in the present paper, but it is possible that a more comprehensive study of the wing in generalized insects will reveal that we do not yet understand the true homologies of the veins in the postcubital region.

All the veins of the wing are subject to secondary forking and to union by cross veins. In some orders of insects the cross-veins are so numerous that the whole venational pattern becomes a close network of veins and cross veins. (Figs. 7, 8, 9.) Ordinarily, however, there is a definite number of cross veins having specific locations as indicated in the diagram. (Fig. 10 A.)

Articulation of the wings.—The simplest structure in the articular parts of the wing is that shown by the dragon flies and May flies, since the wings of these insects are adapted to movements of flight only, and, as a consequence, possess only the flight mechanism. In the wings of insects that flex the wings, there is superadded to the apparatus of flight a mechanism for folding the wings. The dragon flies and May flies are commonly regarded as being descendants of a more primitive ancestral stock than that of the wing-flexing insects; but the question as to whether their articular mechanism is primitive, or derived from a more complicated mechanism, will not be discussed here. The dragon fly wing base may be taken as a starting point in a descriptive sequence, however, because of its simplicity.

Each wing of a dragon fly is attached to the body by two large basal plates. (Fig. 11 A.) The first plate we may call the *humeral plate* (*HP*), the second the *axillary plate* (*AxP*). The humeral plate,

though as large as the other, bears only the first vein of the wing (*C*), which has a small, intermediary piece (*c*) at its base. The axillary

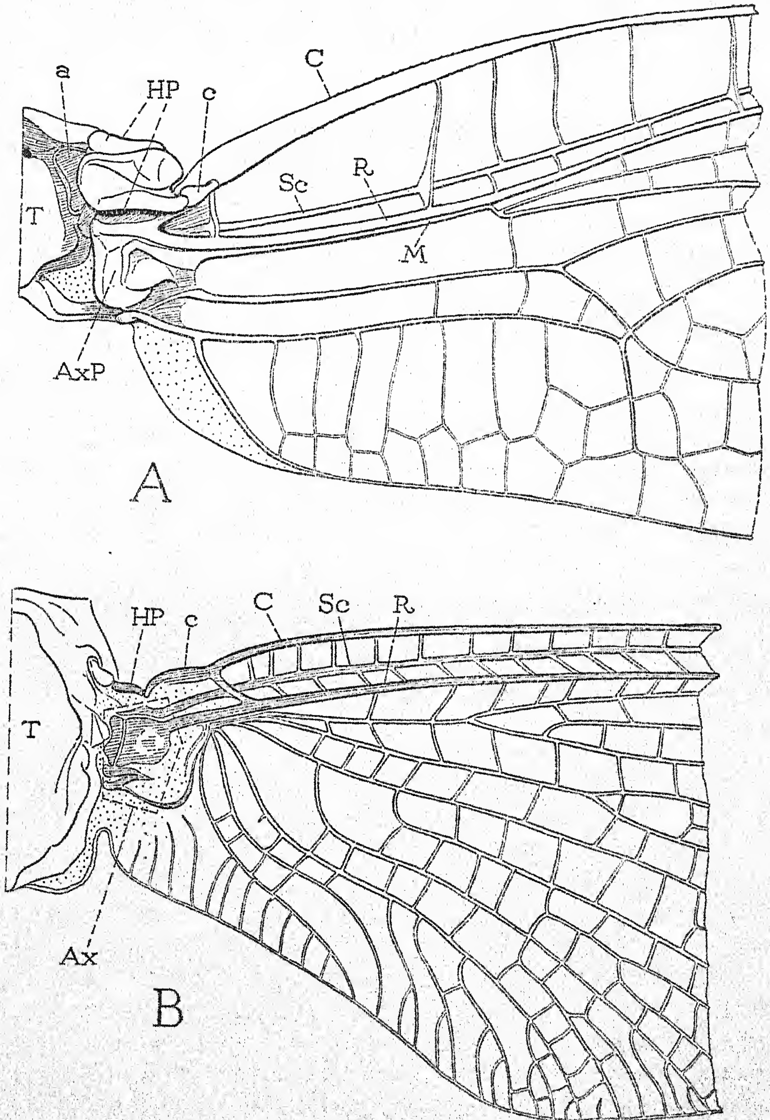


FIGURE 11.—Basal structure of wing of a dragon fly and a May fly, insects that do not flex the wings posteriorly over the back. A, Basal part of forewing of a dragon fly (*Anax junius*); *a*, detached plate of tergum; *AxP*, axillary plate; *C*, costa; *c*, small sclerite at base of costa; *HP*, humeral plate; *M*, media; *R*, radius; *Sc*, subcosta; *T*, tergum. B, Basal part of forewing of a May fly; *Ax*, axillary region corresponding with axillary plate of dragon fly's wing (*AxP* o A); other lettering as on A.

plate carries the four basal shafts of the other wing veins, which are all directly attached to it. The humeral plate is hinged to the anterior

half of the lateral edge of the tergum, or back plate (*T*), of the segment supporting the wings, or sometimes to a distinct sclerite (*a*) of the tergum. The axillary plate is articulated to the posterior half of the lateral tergal margin opposite a deep membranous area of the latter. The wing base is supported from below by the wing process of the pleural wall of the segment, one branch of it articulating with the humeral plate, another with the axillary plate.

The basal plates of the dragon fly's wing turn up and down on the fulcral arms when the wings are lifted or depressed. The two plates, however, are slightly movable on each other, and, since the costal vein (*C*) is doubly hinged to the humeral plate by the small intermediary piece (*c*) at its base, the costal area of the wing can be quite freely deflected independent of the rest of the wing area, which is solidly supported on the axillary plate by the veins attached to the latter.

The May flies, or Ephemerida, are the only other order of modern insects that do not flex the wings. At first sight the base of the May fly's wing (fig. 11 B) appears to have little in common with that of the dragon fly (*A*). On closer inspection, however, it is seen that the chief difference consists of a great reduction in size of the humeral plate (*HP*), and a breaking up of the region of the axillary plate (*AxP*) into a number of irregular sclerotizations. The humeral plate (*HP*) becomes a small sclerite on the anterior margin of the wing base intermediating between the base of the costal vein (*C*) and a small lobe of the dorsal wall of the segment supporting the wing. The small plates of the axillary region (*Ax*) in the May fly suggest, as we shall presently see, the definite sclerites of the flexor mechanism in insects that fold the wings horizontally over the back.

In all insects that flex the wings, the major part of the wing base is occupied by a number of small sclerites which lie between the edge of the supporting tergum and the proximal ends of the veins. These axillary sclerites, or *axillaries* (fig. 12), have definite and constant relations not only to the tergum and the veins, but also to one another, though they vary much in details of form, and certain pieces are sometimes lacking. Three sclerites, however, are practically always present (*1Ax*, *2Ax*, *3Ax*), and in some insects there is a fourth (fig. 10 B, *4Ax*), while at least one or two accessory plates (fig. 12, *m*, *m'*) are usually associated with the more constant sclerites. The humeral plate of the wing base is generally small (*HP*), and may be absent, but it is often relatively large though never attaining the size it has in the wing of a dragon fly (fig. 11 A, *HP*). When the humeral plate is present the costal vein (*C*) is associated with it. The other veins are related to the sclerites of the true axillary region.

The axillary sclerites have in general the following characteristics and relationships: The *first axillary* (fig. 12, *1Ax*) lies next to the body in the anterior part of the axillary region of the wing base, and is

articulated by a longitudinal hinge to the edge of the tergum (*T*). Its anterior end is curved outward and usually is connected with the base of the subcostal vein (*Sc*). The *second axillary* (*2Ax*) lies distal to the first, and is obliquely hinged to the outer edge of the latter. This sclerite is the pivotal plate of the wing base since its ventral surface rests upon the pleural wing process. (Fig. 13, *WP*.) The radial vein (fig. 12, *R*) is flexibly attached to its outer end, and the point of union (*d*) constitutes the principal hinge of the anterior part of the wing with the axillary elements. The *third axillary* (*3 Ax*) lies posterior to the other two with its long axis transverse. Its proximal end articulates

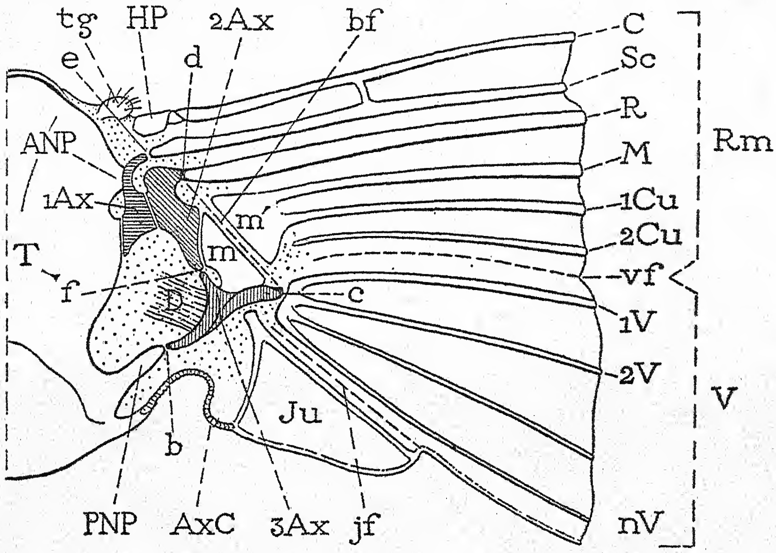


FIGURE 12.—Diagram of basal structure of wing in wing-flexing insects. *ANP*, Anterior notal wing process; *1Ax*, *2Ax*, *3Ax*, first, second, and third axillaries; *AxC*, axillary cord; *b*, articulation of third axillary with tergum; *bf*, basal fold of wing, plica basalis; *C*, costa; *c*, distal end of third axillary; *1Cu*, first cubitus; *2Cu*, second cubitus; *D*, flexor muscle; *d*, articulation of radius with second axillary; *e*, articulation of subcosta with first axillary; *f*, articulation of third axillary with second axillary; *HP*, humeral plate; *jf*, jugal fold of wing, plica jugalis; *Ju*, jugal region; *M*, media; *m*, proximal median plate; *m′*, distal median plate; *n V*, last vannal vein; *PNP*, posterior notal wing process; *R*, radius; *Rm*, remigial part of wing; *Sc*, subcosta; *T*, tergum; *tg*, rudiment of tegula; *V*, vannal part of wing; *1V*, *2V-n V*, first to last vannal veins; *vf*, vannal fold of wing, plica vannalis

with the tergum, and its distal extremity supports the bases of the posterior group of wing veins (*V*). A process on the basal part of the third axillary gives insertion to a muscle (*D*) which arises on the lateral wall of the segment. The third axillary and its muscle constitute the motor elements in the flexor mechanism of the wing. When a *fourth axillary* is present it intervenes between the base of the third and the tergum. In the distal part of the axillary region there are usually one or more accessory *median plates* (*m*, *m′*) associated with the bases of the median and cubital veins. The median plates are more variable than the well-defined axillaries; the proximal one (*m*) is usually attached to the distal part of the third axillary.

Since the wing is a double-walled fold projecting from the body, its basal part (fig. 12) is two-layered, one layer being continuous with the tergal wall of the segment, the other with the pleural wall. The axillary sclerites are contained in this articular region. On the humeral angle of the latter is a small lobe (*tg*), in some insects developed into a scale overlapping the wing base, and known as the tegula. The posterior part of the wing base is membranous, and its posterior border is thickened and corrugated, giving the appearance of a marginal ligament, or *axillary cord* (*AxC*), continued from the posterior angle of the tergum a varying distance into the posterior margin of the wing.

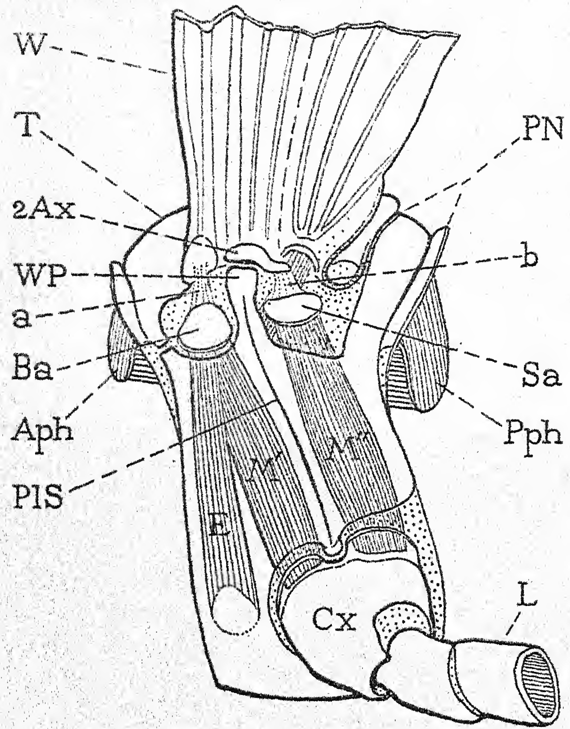


FIGURE 13.—Diagram of the pleural elements of the wing mechanism, left side of a segment. *a*, Membranous connection of basalar sclerite (*Ba*) with anterior angle of wing base; *Aph*, anterior phragma; *2Ax*, ventral plate of second axillary; *b*, membranous connection of subalar sclerite (*Sa*) with second axillary (*2Ax*); *Ba*, basalare; *Cx*, coxa; *E*, pleural muscle of basalare; *M′*, coxal muscle of basalare; *M″*, coxal muscle of subalare; *PlS*, pleural suture; *PN*, postnotum; *Pph*, posterior phragma; *Sa*, subalare; *W*, base of wing, elevated; *WP*, pleura wing process

The ventral support of the wing is the same in all insects, consisting of the pleural wing process (fig. 13, *WP*) which rises from the pleural wall of the segment and forms a fulcrum for the wing base. In insects that have axillary sclerites, the second axillary (*2Ax*) rests directly upon the wing process. Lying in the membrane beneath the wing base, anterior and posterior to the fulcrum, are usually two sclerites (*Ba*, *Sa*) intimately associated with the wing. The first is the *basalare* (*Ba*), the second the *subalare* (*Sa*). Both sclerites are derived, not from the wing, but from the upper edge of the pleural wall, and in some adult insects the basalare remains as a partly detached lobe of the latter. These two epipleural plates are important elements of the wing mechanism, for, as we shall see, they form insertion points for two large wing muscles. The basalare is connected by a ligamentous

thickening (a) of the membrane beneath the wing base with the humeral angle of the wing; the subalare is similarly connected (b) with the second axillary sclerite.

The wing regions.—The wings of all insects are more or less asymmetrical in form; not only is the front margin of each wing always of a different contour from the hind margin, but the pattern of the anterior veins never matches that of the posterior veins. There is a tendency for the anterior veins to become crowded toward the forward margin in such a manner as to give rigidity to the front half of the wing while the posterior veins are more widely spaced, allowing of a flexibility in the rear half of the wing. This arrangement of the veins, together with the antero-posterior difference in the form of the wing, is clearly an adaptation for giving greater efficiency to the wings as organs of forward flight, notwithstanding the fact that many insects can fly backward and sidewise. As a result of the functional differences in the parts of the wing, the wing area becomes differentiated

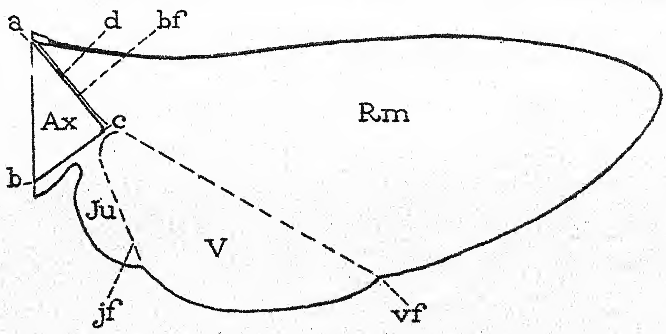


FIGURE 14.—Principal wing regions in insects that flex the wings. *a–b*, Base of axillary region; *Ax*, axillary region; *bf*, basal fold of wing, plica basalis; *c*, apex of axillary region; *d*, point of articulation of radia vein with second axillary (see fig. 12); *jf*, jugal fold, plica jugalis; *Ju*, jugal region; *Rm*, remigium, remigial region; *V*, vannus, vannal region; *vf*, vannal fold, plica vannalis

structurally into several regions. The wing regions are particularly well defined in insects that flex the wings, because the wing folding could not be allowed to interfere with the function of flying, and, therefore, the adaptations for flexing have to follow the structural plan primarily laid down for purposes of flight.

We have already seen that there is at the base of each wing an axillary region, represented by the second plate of the dragon fly's wing (fig. 11 A, *AxP*), which becomes broken up into a number of definite axillary sclerites in the wing-flexing insects (fig. 12). The region of the axillary sclerites has in general the form of a scalene triangle (fig. 14, *Ax*) with its base (a—b) against the body and its longer side anterior to the apex (c). The base of the triangle is the hinge of the wing with the body; the apex represents the distal end of the third axillary sclerite (fig. 12, *3Ax*), which carries the bases of the vannal veins; the point d on the anterior side of the triangle (fig. 14)

marks the articulation of the radial vein (fig. 12, *R*) with the second axillary sclerite (*2Ax*). The rôle that the axillary triangle plays in the folding of the wing will be discussed in Section IV of this paper.

The area of the wing distal to the axillary region comprises the three parts of the wing separated by the vannal and jugal folds (fig. 10 B, *vf*, *jf*), when these folds are present. The area anterior to the vannal fold (fig. 14, *Rm*), containing the costal, subcostal, radial, medial, and cubital veins (fig. 10 B), is the part of the wing chiefly productive of the movements of flight, since it is directly affected by the motor-wing

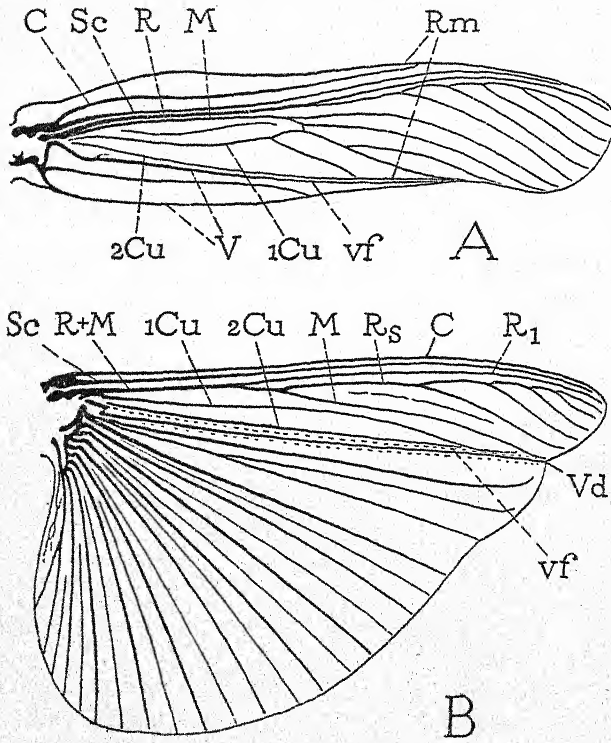


FIGURE 15.—The wings of a grasshopper (*Dissosteira carolina*). A, Left fore-wing. B, Left hind wing. Lettering as on Figure 10 B. The great fan of the hind wing posterior to the vannal fold (*vf*) is possibly the combined vannal and jugal regions

muscles. This part of the wing, therefore, we may term the *remigial area* of the wing (Latin remigium, an oar). The region between the vannal and jugal folds is the part of the wing here termed the *vannus*, or vannal region (fig. 14, *V*), though ordinarily called the anal region. The vannal veins typically spread out like the ribs of a fan, and, as we have seen, their bases are associated with, or supported by, the distal end of the third axillary sclerite. (Fig. 10 B.) In some insects the vannus becomes so large, as in the hind wings of grasshoppers and katydids (fig. 15 B), that it forms an efficient gliding surface which

enables the insects to sail through the air with comparatively little movement of the wings. Proximal to the vannus is the *jugal region* (fig. 14, *Ju*), usually a small membranous area or lobe at the base of the wing, but sometimes much enlarged (fig. 16).

III. THE WING MUSCLES

The musculature of an insect's wing is very simple, considering the nature of the wing movements and the fine adjustments of the latter that the muscles are able to produce. The effect of the muscles on the wings depends largely on the manner in which the wings are attached to the body and on the details of structure in the wings themselves.

In the majority of insects, all the movements of the wings are accomplished by five principal pairs, or paired sets, of muscles in each wing segment. Anatomically the wing muscles belong to three groups, namely, dorsal longitudinal muscles, tergo-sternal muscles, and pleural muscles. Considering the manner in which they effect move-

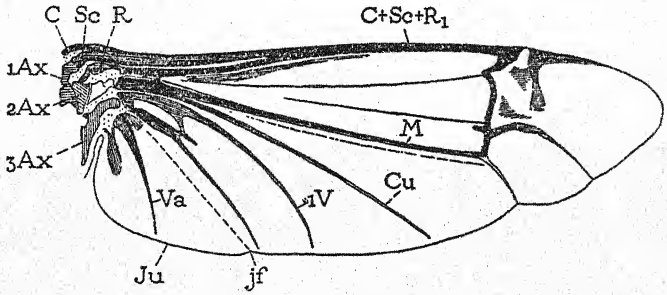


FIGURE 16.—Hind wing of a blister beetle (*Epicauta marginata*), showing the large jugal region (*Ju*).

ment in the wings, however, they are usually classed as "indirect wing muscles" and "direct wing muscles," the first class being the dorsal and tergo-sternal muscles, the second the pleural muscles. Functionally, each of the five sets of muscles must be considered individually.

If the wings of insects originated, as we have supposed, from movable flaps of the body wall extending laterally from the edges of the back plates of the body (fig. 6), they had primarily at their disposal for motor purposes only the muscles of the body segments supporting them. These muscles comprised the longitudinal intersegmental muscles, and possibly dorsoventral intrasegmental muscles. The dorsal longitudinal muscles, by pulling lengthwise on the backplates, could arch these plates upward between the two ends in each segment. Thus, considering that the wing lobes were extensions of the terga, and were supported near their bases on the upper edges of the pleural walls of the segment, each lobe could be given a downward movement by an upward flexure of the tergum just as a pump handle

might be lowered by raising the piston. All modern insects, with a few exceptions, produce the downstroke of the wings at least in part by the contraction of the dorsal thoracic muscles. (Fig. 17 C, *A*.) In response to the new function thus thrust upon them, these muscles in the two wing-bearing segments have become greatly enlarged. (Fig. 18, *81*, *112*.) The elevation of the wings, on the other hand (fig. 17 A), involves a depression of the back plate (*T*) of the wing-supporting segment, and this is accomplished by a contraction of the vertical, or tergo-sternal, muscles of the segment (*C*), just as the pump handle might be raised by pulling down on the piston. It is a question whether the tergo-sternal muscles of the wing-bearing segments were a part of the primitive musculature of the segments, or whether they are specially acquired wing muscles; but, whatever their origin, they are always very large in the two segments (mesothorax and metathorax) that carry the wings (fig. 18, *83*, *84*, *113*), while they are either absent or doubtfully represented in other segments of the body.

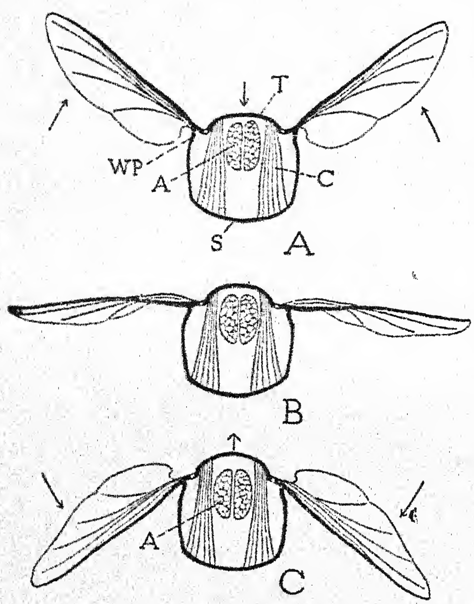


FIGURE 17.—Diagrams suggesting the indirect action of the segmental muscles on the wings, and the torsion of the wings in flight, anterior view. A, The wings elevated on pleural wing processes (*WP*) by depression of tergum (*T*) caused by contraction of tergo-sternal muscles (*C*); hind margins of wings deflected. B, C, The wings depressed by an elevation of tergum caused by contraction of dorsal longitudinal muscles (*A*); hind margins of wings elevated

The segmental muscles that move the wings owe their efficiency to the fact that each wing is pivoted a short distance beyond its base on a strong fulcrum of the lateral wall of the segment. (Fig. 17 A, *WP*.) The degree of movement in the back plate, or tergum (*T*), of the segment necessary to produce the up-and-down strokes of the wings is very small. In freshly killed specimens of flies and bees the wings respond instantly to the least downward pressure on the back of the segment, or to a gentle lengthwise compression of the thorax.

True flight, as we have already observed, is not to be accomplished by mere upstrokes and downstrokes of the wings. Each wing must have a propeller movement in order to produce motion through the air; the plane of the wing must dip forward and downward with each

downstroke (fig. 17 C), and must then reverse itself during the upstroke (A). The ability of the insect wing to make these compound movements depends in part upon the interrelations of the articular sclerites, and in part on the structure of the wing itself. The anterior crowding of the principal wing veins stiffens the forward part of the wing and leaves the expanded posterior area relatively weak and flexible. When the wing is depressed, therefore, its posterior part turns upward (fig. 17 C) as a result of the increased air pressure below, and and thus gives a forward thrust to the wing, with the result that the

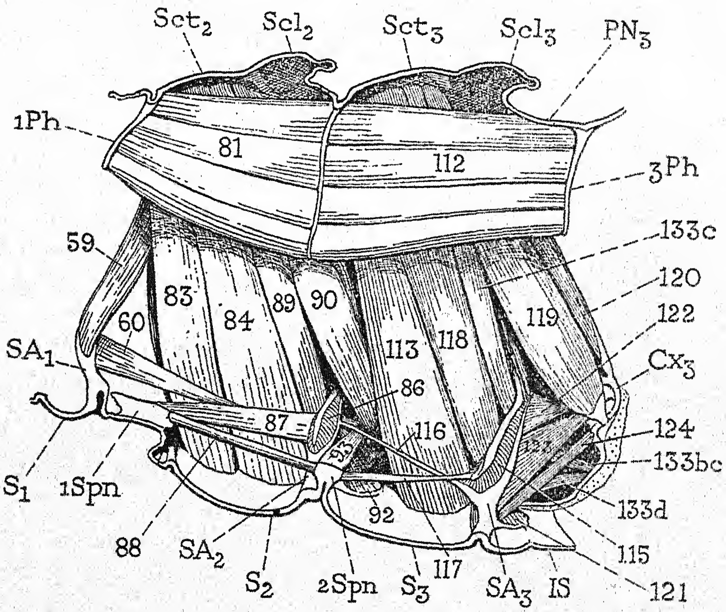


FIGURE 18.—Muscles in the right half of the wing-bearing segments of a grasshopper (*Dissosteira*) as seen from the median plane of the body. *81* ,*112*, The longitudinal dorsal muscles which, by contraction, arch the terga plates upward and thereby depress the wings; *83*, *84*, and *113*, the tergo-sternal depressors of the tergal plates, which indirectly elevate the wings. The other muscles are muscles of the legs and of the sterna

anterior margin goes downward and forward. For the same reasons the counterstroke has a reverse movement (A).

It is possible that the structure of the wing and its automatic response to air pressure enabled the primitive winged insects to fly by means of the dorsal and tergo-sternal segmental musculature alone. Nearly all modern insects, however, have powerful adjuncts to the primitive motor mechanism of the wings in the pleural muscles that affect directly the movements of each wing. These so-called "direct" wing muscles (fig. 19, *E*, *M'*, *M''*) are inserted in adult insects either immediately on the wing bases or on the small sclerites beneath the wings (figs. 13, 19, *Ba*, *Sa*) or, in some cases, on a lobe of the lateral wall of the segment; they have their origins, in nearly

82822—30——27

all cases, on the pleura and on the basal segments, or coxæ, of the legs (fig. 19, *Cx*). In the young of insects that resemble the adults in bodily form, however, these same muscles are inserted on the dorsal edges of the lateral walls of the wing-bearing segments. It appears highly probable, therefore, that the coxal basalar and subalar wing muscles of adult insects are in origin leg muscles that have been given over to the service of the wings. The function of these muscles will be more particularly described in the following section.

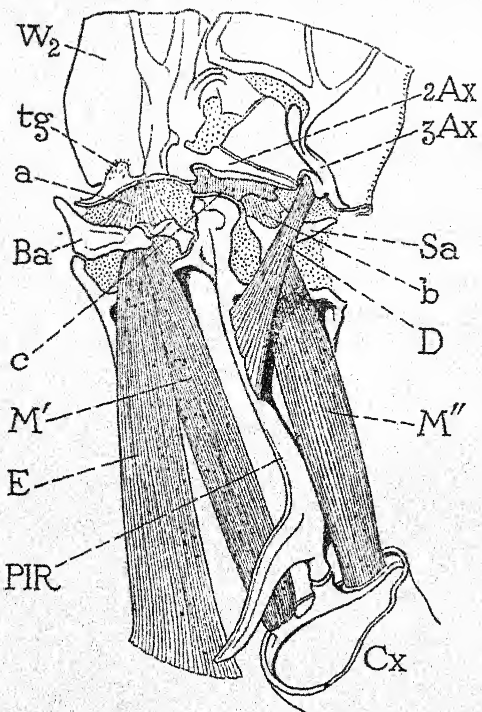


FIGURE 19.—The pleural wing muscles of the mesothorax of a grasshopper (*Dissosteira*), inner view of right side. *a*, Membranous connection of basalar sclerites (*Ba*) with humeral angle of wing base; *2Ax*, dorsal plate of second axillary; *3Ax*, third axillary; *b*, connection of subalare (*Sa*) with second axillary; *Ba*, basalar sclerites; *c*, ventral plate of second axillary; *Cx*, coxa; *D*, flexor muscle of wing; *E*, pleural basalar muscle; *M′*, coxo-basalar muscle; *M″*, coxo-subalar muscle; *PlR*, pleural ridge; *Sa*, subalare; *tg*, rudiment of tegula; W_2, mesothoracic wing, turned upward

The muscle of the basalar sclerite arising on the coxa (fig. 19, *M′*) is usually supplemented by a branch or a second muscle (*E*) arising on the lateral wall of the segment, or on the sternum. The basalar sclerite, as we have seen, is intimately attached to the humeral angle of the wing base by a thickening (*a*) of the intervening membrane. The subalar muscle (fig. 19, *M″*) is always a large muscle, and, through the attachment (*b*) of the subalar sclerite with the second axillary sclerite of the wing base (*2Ax*) it pulls downward on the base of the wing immediately behind the fulcral support (*WP*).

In the dragon flies the homologues of the basalar and subalar muscles of other insects are inserted by strong "tendons" that are attached directly on the wing bases, the first on the humeral plate (fig. 11 A, *HP*) the second on the axillary plate (*AxP*). Furthermore, the ventral ends of these muscles in the dragon flies take their origin on the lower edge of the pleural wall of the segment, their bases evidently having been transferred from the coxa to the body wall. In the flies (Diptera) the base of the subalar muscle has undergone a similar transposition.

The fifth set of wing muscles are the wing flexors. The flexor of each wing is usually a small muscle, or a group of small muscles (fig. 19, *D*), the fibers of which have their origin on the pleural wall of the segment and are inserted directly on the third axillary sclerite of the wing base (fig. 12, *3Ax*). The flexor muscles are present in nearly all insects, including the dragon flies which do not fold the wings; in insects having a special flexor mechanism in the wing base they appear to accomplish the entire movement of flexion.

Various other small muscles are often associated with the wings; they arise on the upper parts of the pleural walls of the wing-bearing segments and are inserted either on the tergum near the wings or directly on the wing bases. Since these muscles are not of constant occurrence and differ in different groups of insects, they need not be considered in a general discussion.

IV. THE WING MOVEMENTS

The motions of insects' wings fall into two distinct categories; those of one include the movements of flight, those of the second embrace the movements of flexion and extension. The flight movements are common to all winged insects; the movements of flexion and extension pertain only to insects that fold the wings horizontally over the back when not in use.

The movements of flight.—The movements of the wings that make flight possible consist of an *upstroke*, a *downstroke*, a *forward movement*, a *rearward movement*, and a *partial rotation* of each wing on its long axis.

It was formerly supposed that the torsion of the wings, including the horizontal and rotary movements, is entirely the result of air pressure on the wings as they are vibrated in a vertical direction. This idea was elaborated particularly by Marey (1874). There is no doubt that the wings do respond by a differential action in their planes to air pressure alone. It has been shown by Bull (1904a) that the wing of a dragon fly attached to a vibratory apparatus in a vacuum jar takes on the rotary movement automatically when air is admitted. Later, however, Bull (1910) observed that the stump from which a wing has been severed in a living insect is deflected forward with the downstroke and takes a reverse position during the upstroke. It is now conceded by students of the insect wing mechanism that the movements of the wing, though in part automatically possible by air pressure, are all produced, or at least augmented, by the action of the wing muscles. Directive movements of the wings, it must be observed, are only possible through muscular and nervous control.

The upstroke of the wing, as we have seen, is produced by the simple device of depressing the back plate, or tergum, of the segment bearing the wings(fig. 17 A), the action being the result of a contrac-

tion of the vertical, tergo-sternal muscles (figs. 17 A, 20, *C*). The mechanism of the upstroke, therefore, is that of a lever of the first class, the fulcrum being the pleural wing process (*WP*) upon which the base of the wing rests. The tergo-sternal muscles are often large and powerful, suggesting that the upstroke of the wings is an important contributant to the force of flight.

The downstroke of the wings is not the work of a single set of muscles. It results in part from the restoration of the dorsal curvature of the back by the contraction of the dorsal longitudinal muscles (fig. 17 C, 20, *A*; fig. 18, *81*, *112*), which are the segmental antagonists of the tergosternal muscles; but probably an important effector of the wing depression in most insects is the posterior pleural muscle (figs. 13, 19, *M″*) inserted on the subalar sclerite (*Sa*). The subalar sclerite, as we have seen, is in immediate connection with the second axillary of the wing base (*2Ax*), and a pull upon the subalar muscle strongly depresses the wing.

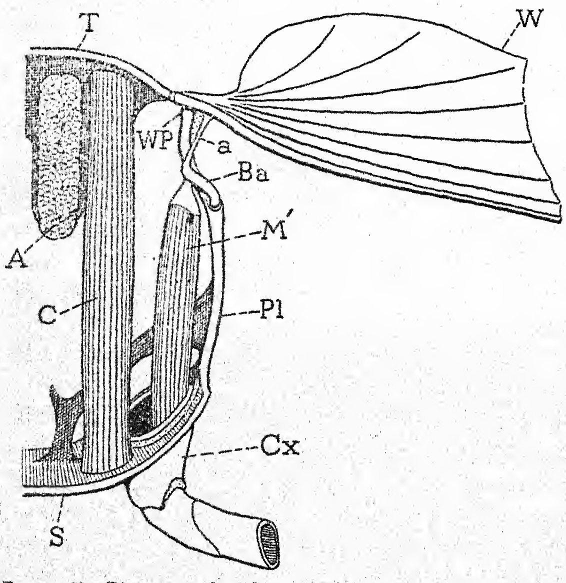


FIGURE 20.—Diagram of the "direct" and "indirect" wing muscles in left half of a segment, anterior view. *A*, Section of longitudinal dorsal muscle ("indirect" depressor of the wings); *a*, membranous connection of basalare (*Ba*) with base of wing; *Ba*, basalare; *C*, tergo-sternal muscle ("indirect" elevator of the wing); *Cx*, coxa; *M′*, coxo-basalar muscle ("direct" pronator-extensor of the wing); *Pl*, pleuron; *S*, sternum; *T*, tergum; *W*, wing; *WP*, pleural wing process

The forward and rearward movements of the wing during flight are of small extent, but of much importance. They evidently are produced by the anterior and posterior pleural muscles (figs. 13, 19, *E*, *M′*, and *M″*) pulling on the wing base, respectively before and behind the pleural fulcrum (*WP*).

The rotation of the wing on its long axis accompanies the anterior and posterior movements, and is produced by the same muscles, namely, the muscles of the basalar and subalar sclerites. The first (fig. 20, *M′*) pulling downward on the basalare (*Ba*) turns this sclerite inward on the upper edge of the pleuron (*Pl*), and the connection (*a*) of the basalare with the humeral angle of the wing base deflects

the anterior part of the wing as it turns it slightly forward. The mechanism of deflection, including the basalar sclerite and its muscle, has been called the *pronator apparatus* of the wing. The movement of pronation accompanies the depression of the wing. (Fig. 17 C.) The reverse movement, or the deflection of the posterior part of the wing accompanying the upstroke (fig. 17 C), is probably caused mostly by air pressure on the expanded, flexible posterior area of the wing surface, but it is likely that the tension of the posterior pleural muscle (figs. 13, 19, M''), pulling on the second axillary sclerite posterior to the fulcrum, contributes to the posterior deflection of the wing during the upstroke.

The motion of each wing in flight is, then, the resultant of its several elemental movements. During the downstroke the wing goes from above downward and forward; its anterior margin is deflected and its posterior area turns upward. (Fig. 17 C.) During the upstroke, the wing goes upward and backward, and its posterior surface is deflected (A).

By comparing the movements of an insect's wings in motion with the action of the blades of an airplane propeller, it will be seen that there is a similarity between the two. The planes of the propeller blades are so turned that each blade in rotating to the right cuts downward through the air with a forward slant, while on the left it goes upward with a rearward slant. The edge of the blade that opposes the air, moreover, is beveled in such a manner that it lies in the plane of rotation. The insect wing differs from the propeller blade in that, by its flexibility, it can successively adapt the different parts of its surface to the same changes in relative position during an up-and-down movement that the rigid propeller blade assumes in revolution. The mechanical effect produced by the two instruments is the same, as we shall see in the next section of this paper.

As a result of the compound movements of the vibrating insect wing, the tip of the wing, if the insect is held stationary, describes a curve having the form of a figure 8. This fact has long been known; it was first demonstrated visibly by Marey (1869, 1874) who attached bits of gold leaf to the wing tips of a wasp and observed the luminous figures described when a beam of strong light was thrown on the vibrating wings. The movements of the wings have since been studied more accurately, however, by mechanical devices in which the vibrating tips are allowed to touch lightly the surface of a moving sheet of smoked paper, thus inscribing a record of their movements which can be more carefully examined. The most successful studies of this kind are those of Ritter (1911) who constructed an apparatus that would rapidly slide a small board covered with blackened paper past a blowfly secured in such a position that the tip of a vibrating wing

would record its motions on the paper. Figure 21 shows two of the curves obtained by Ritter with this apparatus when the head of the fly was directed opposite the movement of the sliding board. The lines of these tracings, therefore, may be taken to show the track described by the wing tips in normal forward flight. Instead of making a figure 8, the wings of a fly in motion describe a series of open loops in which the downstroke takes the form of an italic curve inclined from above downward and forward, while the reverse stroke goes from below upward and posteriorly. The distance between the loops will depend on the speed at which the insect flies. The rotary movement of the wings is most accentuated in swift-flying insects, such as the dragon flies, bees, and flies, which have relatively

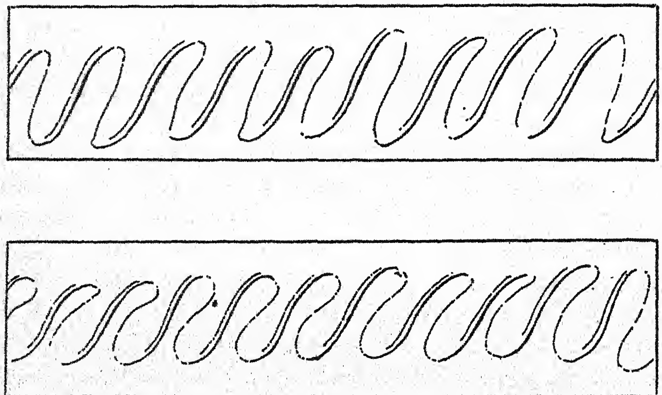


FIGURE 21.—Curves described by the tip of a blowfly's wing in flight. Tracings made by the tip of the wing of a fly held stationary with the head directed toward the movement of the recording surface. (From Ritter, 1911)

narrow wings; in slower-flying insects with broad wings, such as the grasshoppers and butterflies, the up-and-down movement is the principal one.

That the movements of animals, including the flight of insects, could be studied from series of moving-picture photographs was first demonstrated by Marey (1901). With more improved methods, von Lendenfeld (1903), Bull (1904), and Voss (1914) have obtained cinematographic records giving a convincing demonstration of the nature of the insect wing movements in flight. Voss made calulations from his serial pictures of the number of wing strokes a second in many species of insects. However, much of interest might yet be done by this method of research.

The rapidity of the wing movements varies greatly in different insects. The first statements concerning the rate of vibration of insect wings are those of Landois (1867) deduced from observations on the pitch of the sound made by insects in flight. Landois thus estimated that the house fly makes 352 wing strokes a second, a bumblebee 220,

and the honeybee 440 when at its best, though when tired its hum indicates a wing speed of only 330 beats a second. By the same test, the mosquito, it is said, must make as high as 600 wing beats a second. The wing movements have been studied also with mechanical apparatus and from serial photographs. The records of different investigators differ considerably, but it must be recognized that experimental results give at best only the rate at which the insect moved its wings under the conditions of the experiment; it is well known that most insects can vary the speed of their normal flight within wide limits. Marey (1869a) obtained graphic records of the wing beats on a revolving cylinder, and he gives 330 wing strokes a second for the house fly, 240 for a bumblebee, 190 for the honeybee, 110 for a wasp, 28 for a dragon fly, and 9 for the cabbage butterfly. Voss (1914), however, calculating the rate of the wing motion from series of moving-picture photographs, obtained in most cases lower figures; the honeybee, by his test, making 180 to 203 wing strokes a second, the house fly from 180 to 197, the mosquito from 278 to 307, while various other insects have mostly a slower rate. In general, it may be said, the flies and bees have the highest rate of wing movement; most other insects, by comparison, being slow of flight and correspondingly slow in wing motion. The lowest records of wing speed are found among the butterflies and moths, the cabbage butterfly making at best about 9 strokes a second, and some of the noctuid moths about 40; the sphinx moths, on the other hand, are swift flyers and move the wings at a high rate of speed. The reader may find summarized statements on the recorded rates of the wing strokes in insects given by Voss (1914) and by Prochnow (1921–1924).

The movements of flexion and extension.—The movements by which the wings are folded after flight, or extended preliminary to flight, are executed too rapidly to be observed closely in a living insect; but the action of a wing and the operation of the flexor mechanism can be well studied in freshly killed specimens. A grasshopper, a bee, a fly, or most any insect sufficiently large will answer the purpose, but the grasshopper, or particularly the scorpion fly, *Panorpa*, will be found to be a very suitable subject. If the wing of a fresh specimen is slowly folded posteriorly over the back and then brought forward into the position of flight, the accompanying movements of the articular sclerites on one another can be observed, and from their action the probable working of the flexor mechanism in the living insect can be deduced.

First we must look again at the plan of the general wing structure. (Figs. 14, 22 A.) The region of the articular sclerites, or axillaries, forms a triangle at the base of the wing (*Ax*) with its apex (*c*) supporting the base of the vannal region (*V*). When the distal parts of the wing are well differentiated, the vannus is usually separated from

the remigium (*Rm*) by a vannal fold, or plica (*vf*), and the jugal lobe (*Ju*) is separated from the vannus by a jugal plica (*jf*). The axillary sclerites are highly variable in form in different insects, but their relationships to one another and to the bases of the veins are constant. The articulation of the radial vein (fig. 12, *R*) with the second axillary (*2Ax*) lies at the point *d* on the anterior side of the axillary triangle (fig. 22A). The edge of the triangle between this point and the apex (*c*) is formed by the line of flexion, or *plica basalis* (*bf*), between the median plates of the wing base (fig. 12, *m*, *m′*), or between the corresponding areas if the plates are obsolete or absent. The third axillary sclerite (fig. 12, *3Ax*) is the crucial piece of the flexor mechanism. Typically it is essentially Y-shaped, the two prongs being the arms of the mesal part hinged by their tips (*f*, *b*) between the second axillary and a posterior process of the tergum, with the flexor muscle (*D*) inserted in the crotch, while the stalk is the distal arm, the end of which is closely associated with the bases of the vannal veins (*1V*, *2V*) at the apex of the axillary triangle. (Fig. 22 A, *c*.)

When the muscles that keep the wing extended are relaxed, the wing automatically turns a little posteriorly, and a prominent convex fold is formed along the oblique plica basalis (fig. 12, *bf*) at the base of the medio-cubital field of the wing, which is between the two median plates (*m*, *m′*) when these plates are present. At the same time, the third axillary sclerite (*3Ax*) is revolved upward on its basal hinge, or hinges (*b*, *f*), until the insertion point of its muscle (*D*) lies dorsal and slightly mesad to the axis of the hinge. The muscle, which arises on the inner wall of the pleuron below the wing base (fig. 19, *D*), thus acquires an effective purchase on the third axillary, and, by contraction, it evidently now continues the revolution of the sclerite, turning the outer end of the latter (fig. 12, *c*) dorsally, mesally, and forward, until the sclerite is completely inverted and reversed in position. Concomitant with the movement of the third axillary, the first median plate (*m*), which is usually attached to the latter, turns to a vertical position between its hinge with the second axillary (*2Ax*) and its hinge with the second median plate (*m′*), or with the base of the medio-cubital area of the wing, and this line of flexion (*bf*) is swung inward posteriorly until it takes an oblique position extending from in front posteriorly and mesally, overlapping the posterior part of the second axillary.

The movements of the third axillary and the attached median plate (*m*), caused by the contraction of the flexor muscle (*D*), bring about the flexion of the wing and incidentally whatever folding the wing surface undergoes during flexion. The mesal revolution of the third axillary directly lifts the base of the vannal region of the wing associated with the end of its distal arm, and brings it to a mesal position against the side of the body. At the same time, the upward revolu-

tion of the first median plate (m) on the second axillary ($2Ax$), and the consequent inward swing of the posterior end of the plica basalis (bf) between the two median plates (m, m') turns both the medio-

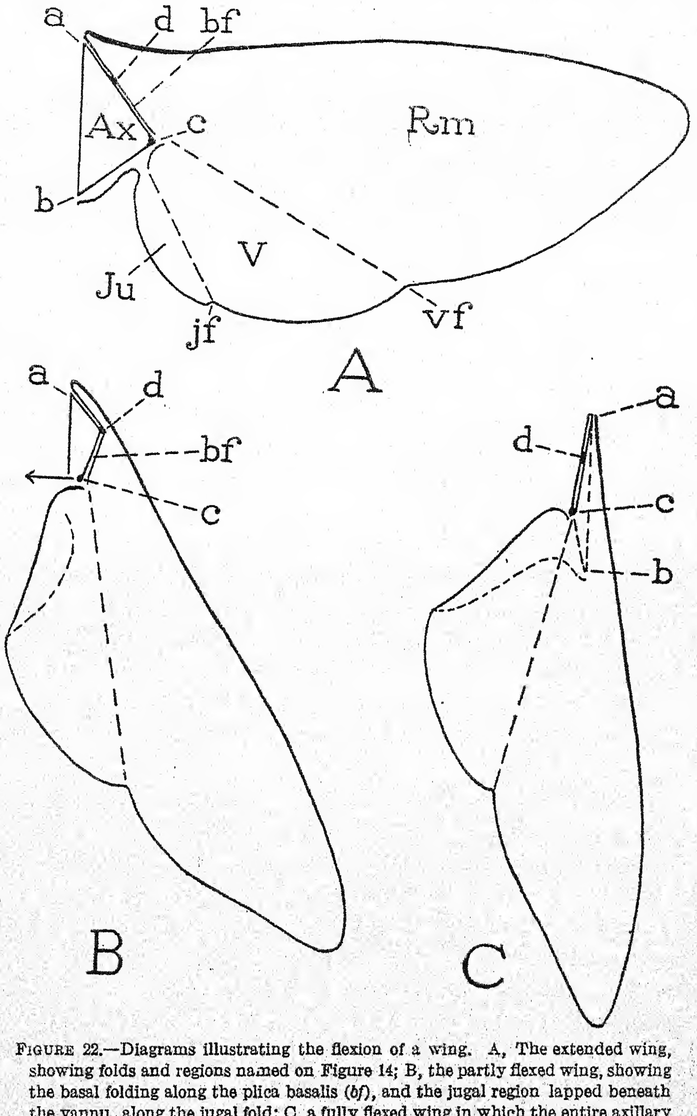


FIGURE 22.—Diagrams illustrating the flexion of a wing. A, The extended wing, showing folds and regions named on Figure 14; B, the partly flexed wing, showing the basal folding along the plica basalis (bf), and the jugal region lapped beneath the vannu along the jugal fold; C, a fully flexed wing in which the entire axillary region is turned vertically on its base (a–b); the vannus is elevated by the apex (c) of the axillary region and turned horizontally against the body; the remigium, turned posteriorly on the point d (see fig. 12), slopes downward and laterally on the flexure at the vannal fold

cubital and vannal areas of the wing posteriorly. The costo-radial area necessarily follows, turning posteriorly on the hinge of the radius (d) with the second axillary, and on that of the subcosta (e) with the

first axillary. As the posterior edge of the wing comes against the side of the body, the jugal lobe (*Ju*) is deflected and turned beneath the vannus along the line of the jugal plica (*jf*). If a vannal plica (*vf*) is present, the remigial region is usually turned downward during the flexion of the wing; but many insects, such as the flies and bees, keep both the remigium and the vannus in a horizontal plane.

The final pull of the flexor muscle is apparently expended on the general wing base, for, in many insects, when the wing is fully flexed, the second axillary is turned into a nearly longitudinal position and is brought close to the side of the back by a vertical revolution of the first axillary on its hinge with the tergum. Thus, in the typical, fully flexed condition of the wing, the first axillary (fig. 12, *1Ax*) stands in a vertical plane on the edge of the tergum; the second axillary (*2Ax*), supported by the first, lies horizontally close to the body; the first median plate (*m*) either stands vertically from the outer edge of the second axillary, or it is inclined mesally and overlaps the latter; the second median plate (*m'*), or the base of the medio-cubital wing area, lies horizontally but makes a sharp fold along the hinge line (*bf*) with the first median plate, the fold crossing the wing base obliquely from the base of the radial vein posteriorly and medially; the third axillary is completely inverted with its apex (*c*) directed mesally and forward. Flexion of the wing does not alter the position of the first and second axillaries in some insects; but the revolution of the third axillary is invariable, showing that it is the motion produced in this sclerite by its muscle, and the consequent folding in the parts immediately affected by its movements, that bring about the rotation of the distal parts of the wing on the basal elements, which constitutes flexion.

The automatic nature of the complicated movements of the wing folding, resulting from the pull of a single muscle, may be roughly demonstrated with a piece of stiff paper cut and creased along the lines of Figure 22 A, but leaving an extension to the left for support. Lifting the apex (*c*) of the axillary triangle, and revolving it on the base (*a*—*b*) to the left (B), will turn the vannal region of the model (*V*) posteriorly and deflex the remigial part (*Rm*). If the apex (*c*) is finally turned mesad of the base line (C), the distal parts of the paper model will take positions quite comparable with those of the parts in a wing of similar form flexed and folded by the revolution of the third axillary sclerite. The details of interaction between the sclerites of the axillary region, and the folding of the latter upon itself, can not, of course, be duplicated unless the entire mechanism is reproduced. A well-constructed model of the base of an insect's wing, made on a large scale, would enable us to understand more accurately the working of the flexor mechanism, and, incidentally, it should be an excellent object for museum display.

The flexing of the wing becomes a still more complicated process if the vannal region is particularly enlarged. In some of the Orthoptera, including most of the cockroaches, the grasshoppers, and the crickets, and in some other insects, the vannus of each hind wing is so much expanded (fig. 15 B) that, when the wing is flexed, it must be plaited and folded up like a fan (fig. 23 B) in order to give space for the rest of the wing. In wings that are plaited during flexion there may be, as in the hind wing of a grasshopper, two lines of folding between the remigium and the vannus with a dividing vein, or *vena dividens*, between them. (Fig. 15 B, *Vd.*) The folding and plaiting of the fully flexed wings of a grasshopper are shown in Figure 23. The narrower

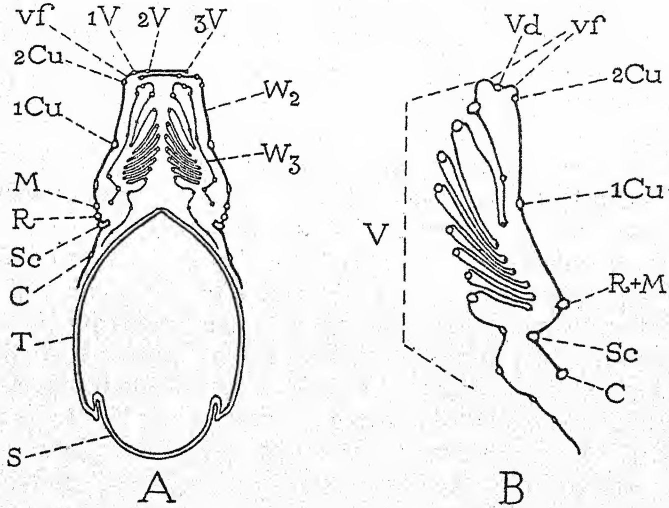


FIGURE 23.—Cross sections through the folded wings of a grasshopper (*Dissosteira*). A, Cross section through the wings and the abdomen; the forewings, or tegmina (W_2), when closed, form a compartment over the back (T) in which are folded the large hind wings (W_3); B, cross section of the right hind wing, posterior view, showing the many plaits of the vannal region (V) which is folded like a fan. Lettering as on Figure 15

forewings, or *tegmina* (A, W_2), overlap each other to form a rooflike covering with steeply sloping sides completely inclosing and protecting the more delicate hind wings (W_3) folded beneath them.

The extension of the wing involves a reversal of the movements of flexion. The flexor muscle must first relax. A contraction then of the anterior pleural muscles (figs. 13, 19, *E*, *M'*), pulling on the humeral angle of the wing base, may extend the wing directly, though the action of these muscles in this capacity is often difficult to demonstrate in a dead specimen. With insects in which the second axillary sclerite is elevated on the outer edge of the first axillary in the fully flexed wing, it is clear that the wing may be extended by the downward pull of the posterior pleural muscle (*M'*) on the second axillary, for a pressure on this sclerite at once restores all the axillary elements to a horizontal

plane and thereby spreads the wing. Some insects may be seen to extend the wings deliberately before taking flight, but with most species flight is practically simultaneous with the wing expansion.

V. FLIGHT

A rotating electric fan throws out a current of air because its inertia is greater than the resistance of the air. An airplane moves through the air because the force of its inertia is less than the force of the air pressure created by its revolving propeller. In other words, any object that can create a current in the surrounding medium, if held stationary, will move itself through the medium contrary to the direction of the potential current if the force of the latter is greater than the inertia of the object. Motion is the result of the difference in density, or pressure, in the medium created by the propeller mechanism on opposite sides of it; the object moves toward the region of lowered pressure.

Flight by any heavier-than-air machine or animal that does not depend on currents or rising columns of air requires a mechanism capable not only of producing a forward motion, but also of creating a lifting force sufficient to overcome the pull of gravity. Soaring birds and gliding planes keep themselves aloft after the manner of a kite; the extent of their area that they oppose to the air sustains them on the air pressure created beneath. The ordinary airplane is driven only forward by the direct action of its propeller; it is lifted by the areas of decreased pressure created above its slanting wings by the force of its forward motion. With most insects the area of the wings is far too small, in proportion to the size and weight of the insect's body, to have much value as a planing surface, and, moreover, the wings are the active elements in the motor mechanism. A small-winged insect, therefore, can neither soar in the manner of the larger birds, nor can it sustain itself in the way the moving airplane does. The wings of insects must furnish not only the driving power, but a lifting force as well, which is to say, the movement of the wings must create a region of lowered pressure both before and above the body of the insect.

An interesting and instructive study of the effect of the wing movements of insects on the surrounding air has been made by Demoll (1918). By means of a simple apparatus consisting of a frame with several horizontal cross bars on which were suspended rows of fine owl feathers, Demoll was able to demonstrate the direction of the air currents created by the wings in vibration when the insect itself is held stationary. The lightness of the feathers made the latter delicately responsive to any disturbance of the air in their immediate vicinity, and thus the air currents set up by the whirring wings of an insect, secured by the body in such manner that the wing movements would not be hindered, were registered in the displacement of the

feathers. Experimenting in this way with insects of different orders, Demoll found that the currents of air drawn toward a stationary insect by the vibrations of its wings come not only from in front, but also from above, from the sides, and from below, and that the currents given off are all thrown out to the rearward. (Fig. 24.) The strength of the currents, however, is not the same from all directions, as is indicated by the relative thickness of the arrows in the diagrams. The air is drawn toward the insect most strongly from before and above the anterior part of the body; the outgoing currents are strongest in a horizontal or slightly downward direction. Most of the oncoming currents, therefore, are turned to the rear in the neighborhood of the insect's body, and condensed in a small region behind it.

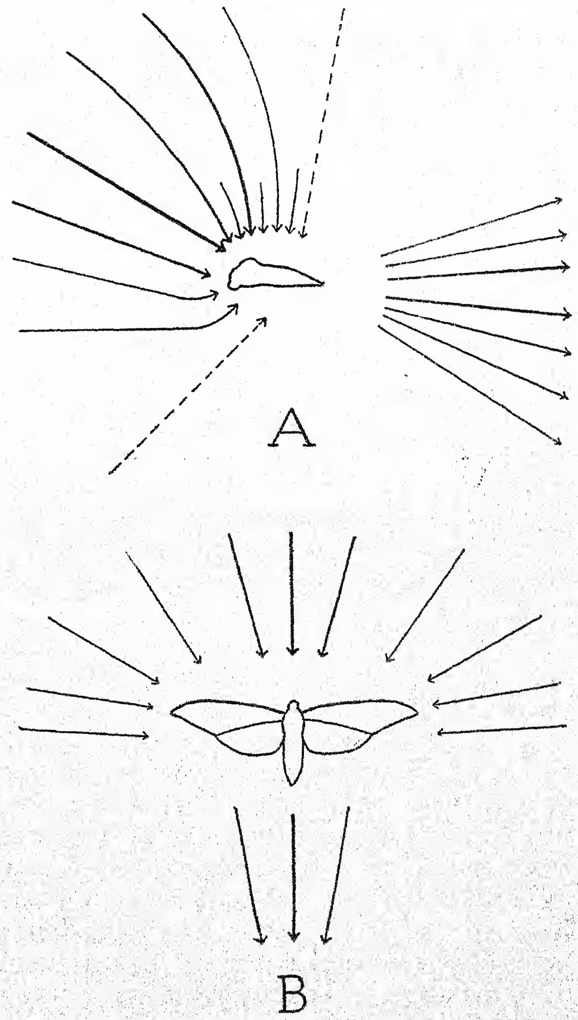


Figure 24.—Diagrams showing the currents of air created by the vibrating wings of an insect held stationary. The thickness of the arrows indicates the relative strength of the currents. (From Demoll, 1918.) A, Lateral view, showing currents in the median vertica plane; B dorsal view, showing currents in the horizontal plane

If the insect is free to move, the mechanical effect of the vibrating wings on the air will be the same as when the insect is held stationary; but, instead of moving the air, or instead of moving the air to the same extent as before, the greater part of the wing force will propel the insect through the air opposite the direction of the air currents created when the insect is secured. The fact that the vibrating wings produce air currents does not mean that the insect will be carried along on the currents of its

own production; in terms of mechanics, as we have seen, the direction from which a current of air is drawn by a stationary object is the direction of lowered pressure, while the opposite is that of increased pressure. According to the observations of Demoll, therefore, when an insect launches itself into the air and starts the vibration of its wings, there is at once created before it and above it a region of decreased pressure, and the convergence of all the currents behind produces here a region of greatly increased pressure. The lowered pressure above counteracts the weight of the insect; the increased pressure behind drives the insect forward into the low-pressure region in front. Thus, Demoll points out, while the soaring bird, with large outstretched wings practically stationary, rests upon the air, the flying insect, with small but rapidly moving wings, is suspended in the air. The bird, a glider plane, or a kite is borne up by increase of pressure below; the insect, on the other hand, is sucked up into the air and held suspended by the partial vacuum that its wings create above it. The flying mechanism of the insect, therefore, is comparable with that of a helicopter airplane, except that in the insect the wings neatly combine the function of two sets of propellers working at right angles to each other. If both propellers of a bi-motored airplane were directed forward and upward, the machine would resemble an insect—if it could fly. The body weight of an insect is so distributed that the center of gravity lies behind the wing bases, usually at the base of the abdomen. (See Demoll, 1918.)

The driving force of the insect's wing movements probably depends upon the angle at which the wing surfaces cut the air. Slow-flying insects with broad wings, such as the butterflies and grasshoppers, keep the wing surfaces almost horizontal and fly more in the manner of small birds with comparatively few strokes of the wings in any unit of time. Some of the large swallowtail butterflies even soar for short distances with the wings held stationary. The more swiftly flying insects, however, having narrow wings, turn the wing surfaces more nearly vertical with each stroke, whether up or down, but as Ritter (1911) says, "the insect flies fastest when the downstroke approaches a vertical direction," because the greater the speed the more the curve of the upstroke is drawn forward in the direction of flight.

The speed of insect flight may be very high, considering the small size of insects. Demoll (1918) gives a table of the rate at which different species fly, obtained by setting individuals at liberty in a room lighted by one window and recording the time in which they flew direct from the dark side of the room to the light. Among the swiftest flying insects, according to this test, are the hawk moths (Sphingidae), a horsefly (*Tabanus bovinus*), and the dragon flies.

The hawk moths made a speed up to 15 meters a second, followed closely by *Tabanus bovinus* going at a rate of 14 meters. A dragon fly (*Libellula depressa*), doing ordinarily 4 meters a second, can make 6 to 10 meters in the same time when flying rapidly. A house fly travels from 2 to 2.3 meters a second; a bumblebee (*Bombus*) from 3 to 5. The honeybee, Demoll says, when flying unladen from the hive, has a speed of 3.7 meters a second, but on the return, if loaded with pollen, its speed is cut down to 2.5 meters for the same unit of time. The pollen load of the bee, according to Demoll, weighs about 20 milligrams, which is approximately 30 per cent of the body weight of the bee.

The ability merely to progress through the air is not efficient flight. The smaller grasshoppers leap into the air and sustain themselves for some distance by movements of the wings, but they have small power of directing their course after they leave the ground. Some of the migratory locusts ascend to great heights and go long distances on the wing, but they are probably dependent largely on the wind for transportation. The Carolina locust is a better flyer, but its course on the wing, though more or less directive, appears to be rather haphazard. Real flight involves the ability to steer a definite course, and to turn this way or that as exigencies demand. By this test the majority of insects are expert flyers, and we need only observe a dragon fly foraging for smaller insects over the water, one of the smaller horseflies dodging the ineffectual counter strokes of its intended victim, or a hawk moth poised in the air as it extracts the nectar from the depths of a corolla, to realize how adroitly insects can make use of their wings in controlling their flight.

Insects are not provided with rudders. There is little evidence that they use their bodies or their legs to direct or alter their course while in the air. Stellwaag (1916), who has made a special study of the steering powers of insects, points out that if directive flight were accomplished by movements of the legs or the abdomen, these movements could be detected in the more slowly flying species, whereas, in fact, no such movements are either visible by close inspection or can be detected by mechanical devices. Shadowgraphs of flying insects, he says, record no alteration in the position of the body or of the legs during a change in the direction of flight. Observations on insects held in a pair of tweezers and turned at various angles also failed to show compensatory movements in the body or appendages. Finally, Stellwaag resorted to experimentation on living insects impaled on slender pins thrust vertically through the thorax. Insects thus secured vibrate the wings as in flight and revolve to the right or the left on the axis of the pin, whether the latter is held vertical or inclined, but the turning is never accompanied by movements of the

legs or abdomen. Steering, therefore, Stellwaag concludes, is evidently accomplished by a differential action in the wings themselves.

With the insects held on pins, it is possible to observe the action of the wings directly; and to make the wing movements more evident Stellwaag employed the method used by Marey of attaching bits of gold leaf to the wing tips and throwing a strong light on them while in motion. In many cases, he says, not only the plane of the wings is seen to be altered as the insects revolves itself on the pin, but there is also visible a change in the amplitude of the wing strokes on one side or the other. From these experiments it is evident that the flying insect must control the direction of its flight after the manner of a rower in a boat, who, in the absence of a helmsman, keeps to his course or alters it by changes in the manipulation of the oars.

The muscles of the insect concerned in the differential action of the wings must be the pleural muscles of the alar segments, which are those of the basalar and subalar sclerites (fig. 19, *E*, *M′*, and *M″*), since these muscles alone have specific connections with the wings. The longitudinal and vertical muscles of the wing-bearing segments, though potent effectors of wing movements, can not unequally distribute their influence between the two sides of a segment.

It is not surprising that insects should be experts on the wing, considering that they have been flying for several hundred million years, but still we are inclined to marvel when we see them perform feats that are as yet quite impossible for our newly developed, heavier-than-air flying machines. In addition to their ability to steer themselves adroitly in forward flight, many insects can go into reverse gear and fly directly backward without altering the position of their bodies, and, moreover, they have also some mechanism of adjustment by which they can fly sidewise, either to the right or left, at right angles to the body axis. The dragon flies are particularly adept in these modes of flight, but many of the smaller insects, such as the flies and bees, are quite equal to the dragon flies in being able to dart suddenly to the side or rearward while the head still points in the direction of the arrested forward flight. Reversed and lateral flying is probably controlled also by the pleural muscles of the flight mechanism, which alone can give an altered or differential action to the wings; but it is remarkable that organs so evidently fashioned for forward flight, as are the wings of insects, can function efficiently for producing motion in other directions.

Still another feat that many insects perform on the wing with seeming ease is *hovering*. Keeping the wings in rapid movement, the insect remains without other motion suspended at one point in the air, even maintaining its position i the face of a slight breeze. Presumably, in hovering, the wings are vibrated approximately in a horizontal plane, thus creating a region of decreased air pressure above the body but not

before it. The rate of the wing movements then must be just sufficient to create a balance with the pull of gravity. A drift on air currents must be counteracted by compensatory changes in the angle of the wing vibrations.

An interesting illustration showing the course taken by a honeybee or by a drone fly approaching a group of flowers is given by Stellwaag. (Fig. 25.) The insect arrives head on, arrests its flight and swings to the right or left still headed toward the flowers; next, it circles about in ordinary forward flight, making a closer approach; now, perhaps, it hovers, again zigzags sideways, and finally goes direct to a particular blossom.

Considering how adept are insects on the wing, it seems certain that they must have a highly developed "sense" of equilibrium. And yet, among the numerous and diverse sense organs with which insects are known to be equipped, organs to which might be assigned a static function, or the control of balance, have been found in very few cases, and principally in certain small forms (Phylloxera) with limited powers of flight. Lacking evidence of the existence of organs of equilibrium generally distributed in insects, we might suppose that the maintenance of balance during flight is an automatic reaction through the sense of sight. The writer has found, however, that a large swallowtail butterfly (*Papilio polyxenes*) is able to fly well after having its eyes thoroughly blackened with a mixture of glue and powdered charcoal until it no longer reacts to light in a room. (The normal butterfly goes at once to a window.) An individual thus blindfolded fluttered about aimlessly in a room with three windows on one side, though before, when liberated, it flew directly to a window. Taken out of doors it immediately flew upward in widening circles, finally going high over the roof of a two-story house and disappearing over the tops of trees beyond. Clearly this insect did not require the use of its eyes to keep itself in the proper position for flying. Another individual of the same species was able to fly in the normal way when its entire head was cut off, though, after the manner of insects lacking a brain, it had no inclination to do so, except when artificially stimulated. When thrown into the air, it fell straight down, but the sudden con-

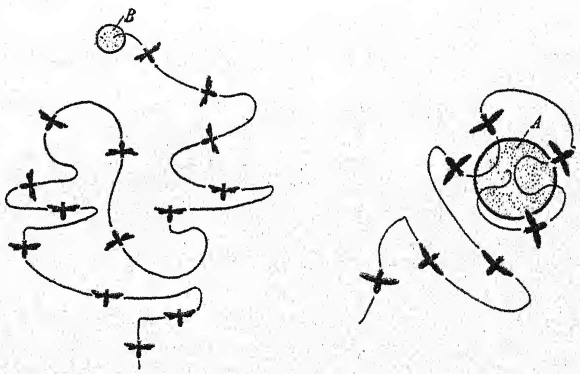


FIGURE 25.—The course taken by a honeybee (*A*) and a drone fly (*B*) approaching a flower. (From Stellwaag, 1916)

tact with the ground stimulated it to make a short flight, during which it was well able to keep its balance. When at rest, it held the wings folded above the back in the usual fashion, though the body tilted somewhat to one side, a result of the loss of "tonus" in the muscles always shown by decerebrated insects.

TEXT REFERENCES AND A LIST OF THE MORE IMPORTANT PAPERS ON THE MECHANISM OF INSECT FLIGHT

AMANS, P. C. (1883, 1884). Essai sur le vol des insectes. *Rev. Sci. Nat.*, Sér. 3, **2**: 469–490; **3**: 121–139, pls. 3–4.

——— (1885). Comparisons des organes du vol dans la série animale. *Ann. Sci. Nat.*, Sér. 6, Zool., **18**: 9–222, pls. 1–8.

AXENFELD, D. (1911). Locomozione aerea degli insetti. *Boll. R. Accad. Medica de Roma*, **37**: 123–136, 7 figs.

BELLESME, J. DE (1879). Sur une function de direction dans le vol des insectes. *C. R. Acad. Sci.*, Paris, **89**: 980–983.

BULL, L. (1904). La chronophotographie des mouvements rapides. *Bull. Soc. Philomath.*, Paris, 9th sér., **6**: 192–199, 9 figs.

——— (1904a). Mécanisme du mouvement de l'aile des insects. *C. R. Acad. Sci.*, Paris, **138**: 590–592.

——— (1909). Recherches sur le vol de l'insecte. *C. R. Acad. Sci.*, Paris, **149**: 942–944.

——— (1910). Sur les inclinaisons de l'aile de l'insecte pendant le vol. *C. R. Acad. Sci.*, Paris, **150**: 129–131.

COMSTOCK, J. H. (1918). The wings of insects. 430 pp., 427 figs. Ithaca, N. Y.

CRAMPTON, G. C. (1916). The phylogenetic origin and the nature of the wings of insects according to the paranotal theory. *Journ. New York Ent. Soc.*, **24**: 1–39, pls. 1, 2.

DEMOLL, R. (1918). Der Flug der Insekten und der Vögel, 67 pp., 18 figs., 5 pls. Jena.

HAUPT, H. (1929). Die Mechanik des Zikadenflügels und ihre Bedeutung für den Flug. *Zeitschr. wiss. Insektenbiologie*, **24**: 73–78, 5 figs.

HOFF, W. (1919). Der Flug der Insekten und der Vögel. *Naturwissenschaften*, **7**: 159–162.

KARNY, H. H. (1925). Einiges über die Gryllacrisarten des Typus IV. *Zeitschr. wiss. Zool.*, **125**: 35–54, 9 figs.

LANDOIS, H. (1867). Die Ton- und Stimmapparate der Insekten in anatomisch-physiologischer und akustischer Beziehung. *Zeitschr. wiss. Zool.*, **17**: 105–184, pls. 10, 11.

LENDENFELD, R. von (1881). Der Flug der Libellen. *Sitz. Ber. Akad. Wiss.*, Wien, Math.-Natur., **83**: Abth. I: 289–376, pls. 1–7.

——— (1903). Beitrag zum Studium des Fluges der Insekten mit Hülfe der Momentphotographie. *Biol. Centrlbl.*, **23**: 227–232, 1 pl.

MAREY, E. J. (1869). Mémoire sur le vol des insectes et des oiseaux. *Ann. Sci. Nat.*, Sér. 5, Zool., **12**: 49–150, 42 figs.

——— (1869a). Recherches sur le méchanisme du vol des insectes. *Journ. Anat. Physiol.*, **6**: 19–36, 337–348.

——— (1872). Second mémoire sur le vol des insectes et des oiseaux. *Ann. Sci. Nat.*, Paris, Sér. 5, Zool., **15**: art. 13, 62 pp., 23 figs.

——— (1874). Animal mechanism: a treatise on terrestrial and aerial locomotion. 283 pp., 117 figs. *Internat. Sci. Series*, New York.

Marey, E. J. (1891). Le vol des insectes étudié par la photochronographie. *C. R. Acad. Sci.*, Paris, **113**: 15–18, 1 fig.

Martynov, A. B. (1925). Über zwei Grundtypen der Flügel bei den Insekten und ihre Evolution. *Zeitschr. morph. Oekol.*, Tiere, **4**: 465–501, 24 figs.

Pettigrew, J. B. (1891). Animal locomotion, or walking, swimming, and flying. 264 pp., 130 figs., London.

Piéron, H. (1927). De la loi qui relie la surface des ailes au poids des individus dans une même espèce animale, et de quelques problèmes concernant le vol des insectes. *C. R. Acad. Sci.*, Paris, **184**: 239–241.

Portier, P., et de Rorthays (1926). Recherches sur la charge supportée par les ailes des Lépidoptères de diverses familles. *C. R. Acad. Sci.*, Paris, **183**: 1126–1128.

Poujade, G. A. (1884). Note sur les attitudes des insectes pendant le vol. *Ann. Soc. Ent. France*, Sér. 6, **4**: 197–200, pl. 8.

Prochnow, O. (1921–1924). Mechanik des Insektenfluges. In Schröder's *Handbuch der Entomologie*, Chapter 9, 534–569, 28 figs.

Ritter, W. (1911). The flying apparatus of the blow-fly. *Smithsonian Miscellaneous Collections*, **56**: No. 12, 76 pp., 19 pls.

Snodgrass, R. E. (1929). The thoracic mechanism of a grasshopper, and its antecedents. *Smithsonian Miscellaneous Collections*, **82**, No. 2, 111 pp., 54 figs.

Stellwaag, F. (1910). Bau und Mechanik des Flug-Apparates der Biene. *Zeitschr. wiss. Zool.*, **95**: 518–550, pls. 19, 20.

——— (1914). Der Flugapparat der Lamellicornier. *Zeitschr. wiss. Zool.*, **108**: 359–429, pls. 11–14.

——— (1916). Wie steuern die Insekten während des Fluges? *Biol. Zentralbl.*, **36**: 30–44, 9 figs.

Tillyard, R. J. (1919). The panorpid complex. Pt. 3, the wing-venation. *Proc. Linn. Soc. N. S. W.*, **44**: 533–718, pls. 31–35.

Voss, F. (1913, 1914). Vergleichende Untersuchungen über die Flugwerkzeuge der Insekten. *Verh. Deut. Zool. Gesell.*, **23**: 118–142, 4 figs.; **24**: 59–90, pls. 1, 2.

CLIMATE AND MIGRATIONS[1]

By J. C. Curry

In separate favoured regions various kinds of men set out to domesticate and master the gifts and forces around them: to "live well," in the old Greek phrase, under the given conditions ~~of~~ their home, or failing this, to seek and make a new one: in either event, to comply as well as to command; to conquer Nature by observance of her laws.

J. L. Myres.

In this wonderful century when discoveries and inventions have followed fast on one another's heels man seems to look dazed and half comprehendingly at the works of his own hands. So that there are some who say that he is on the brink of new and more wonderful mastery over nature; others that there are no more discoveries to make; and others again who wish to cry halt, and ask hopelessly, for 10 years' rest from the innovations and disturbances which scientific inquiry is bringing into their world.

For more than five centuries man's progress has been almost uninterrupted in every direction. During these centuries nature has been strangely quiet; and man has ceased to be frightened of "portents" and "visitations." He has taken advantage of this long quiet period to accumulate knowledge, nearly sufficient, perhaps to enable him to be the "master of his destiny," when next nature rouses herself to such a mood as swept the Roman world into utter ruin. Nearly sufficient, perhaps; but there is still much work to be done before compliance with nature's laws can be wholly intelligent.

It is only possible here to sketch the main outline of the inquiry, concerning man and his environment, most relevant to this issue. The sole justification for so crude a sketch is the hope of suggesting new points of departure for others.

In 1903 the Carnegie Institute of Washington appointed Mr. Ellsworth Huntington to assist Professor Davies of Harvard University in the physiographic work of an expedition into Central Asia. The results of this and of subsequent expeditions were embodied in an account published by Mr. Huntington in 1907.[2] The great interest of his work lies in his presentment of the evidence concerning the relations between the human race and its physical environment; of that

---

[1]Reprinted by permission from Antiquity, a quarterly review of Archæology, September, 1928.

[2]The Pulse of Asia.

concerning the changes in that environment through changes of climate during historic times; and in his treatment of the subject of the effects of these changes on its history.

Briefly stated his main argument is that there is evidence of the recurrence of changes of climate in Central Asia during historic times,

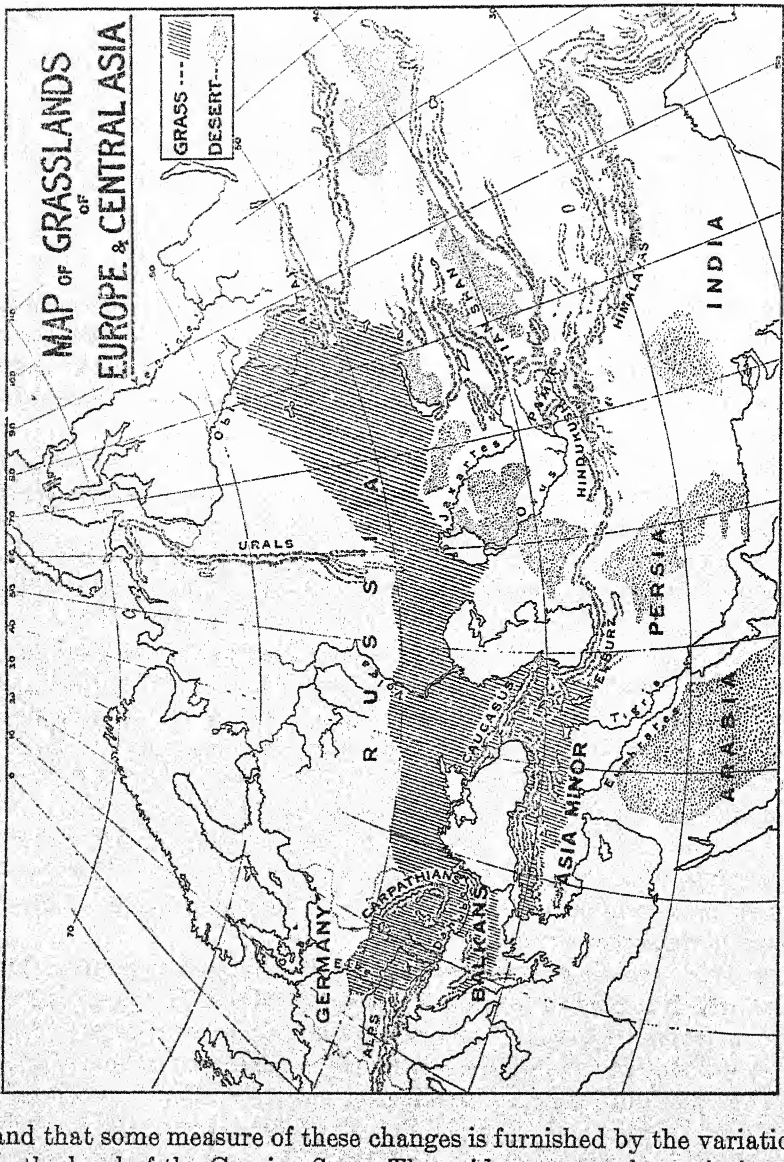


FIGURE 1

and that some measure of these changes is furnished by the variations in the level of the Caspian Sea. The evidence as to the variations in the climatic conditions of other places in Asia confirms that concerning the variations in the level of the Caspian. He maintains that, while

many of the facts might be explained in individual cases by other theories than that of a simultaneous change of climate over a wide area no other theory explains all the facts. A comparison of physiographic, historical and archeological data from Russian Turkestan, Chinese Turkestan, Persia, Seistan, Baluchistan and from the area draining into the Caspian Sea shows that all lines of evidence agree in proving that pulsations of climate, corresponding in time and character, have been common to all these countries. The lakes and rivers throughout the whole of this region have waxed and waned simultaneously more than once since the first records of Herodotus. In his time the Caspian stood at a level more than 150 feet higher than it does at the present day. In the time of Alexander it embraced the Sea of Aral, and the Oxus and Jaxartes then entered it. This latter statement is made on the authority of a survey conducted under the orders of Alexander and his generals. To admit the possibility of this it is necessary to suppose that its level was 150 feet higher than it is at present. From the figures given by Strabo (20 A. D.) it is concluded that at that time the level was from 85 to 100 feet higher than now. In his days the trade route from India to Europe led along the banks of the Oxus, and crossed the Caspian to the mouth of the Cyrus river. Four hundred years later the trade route was diverted from the Oxus to Aboskun in the southeast corner of the sea. About this time the level of the sea was lower than it is now. Walls were built at Aboskun and at Darbend, on the opposite coast, "as a bulwark against the migratory Huns." At the former place the line of the wall can now be traced, below water, at a distance of 18 miles from the shore. At Baku and at other places are ruins of submerged buildings dating either from the fifth or the twelfth centuries. There are several strands at varying heights along the southern shores of the Caspian, among the most clearly marked of which are those 600, 250 and 150 feet above the present level.

Their weak development shows that, as a rule, the sea did not stand at any one level for a long time. The state of their preservation shows that they are of very recent origin.

The most significant feature of the climatic curve of the Caspian Sea is that it is applicable to the whole of western and central Asia. At a distance of 1,000 miles to the east in the Tianshan mountains there are remains of irrigation channels at a level where there is now frost in midsummer and so much moisture that, if agriculture were possible under such conditions, irrigation would be unnecessary. Two thousand miles to the west in Armenia, in the lake of Gyoljuk, the stone houses of a village are standing 20 to 30 feet below its surface. Local records indicate that they were built about 500 A. D.

A survey of six distinct basins, viz., Gyoljuk, the Caspian, the Seistan Lakes, Lop Nor, Turfan, and Kashmir (the latter being south

of the Himalayas), proves that a great change took place in the early centuries of the Christian era.

The only hypothesis which will fit all the facts is that of a change of climate in the direction of greater aridity throughout these regions. Except in Kashmir the change brought disaster. Scores of once prosperous oases were abandoned for lack of water. The inhabitants were driven away in waves of migration to confound the civilized world.

A rainfall of 20 inches a year in Australia has been estimated to make it possible to keep 600 sheep to the square mile. A drop to 13 inches reduces the number to 100; and 10 inches is sufficient for only 10 sheep. A gradual decrease of rainfall in the steppes of Asia would naturally lead to migrations of pastoral nomads from the drier regions to those which offer pasturage for their flocks and herds. As the steppes became drier northern and central Europe were, after a long period of blighting cold, becoming warmer and more and more habitable. History records the coming of horde after horde. Nothing could stay them. Rome and Roman civilization fell before them.

Before we can properly estimate the influence of climatic changes upon history, it is necessary to investigate the nature of those changes, both as to duration and origin, as well as to determine the reasons for supposing that climate varies uniformly over wide areas.

Scientists have recognized two chief types of climatic change. The first is that of the glacial periods; the second is that of the 36-year cycle discussed by Bruckner, Clough, and others. There is good reason to believe that the latter is applicable to the whole surface of the globe. During a cycle there are two extremes, at one of which the climate of continental regions is to a greater extent cool and wet, with a lower barometric pressure and relatively frequent storms for a series of years; at the other it is comparatively warm and dry, with higher pressure and fewer storms. These phenomena are most pronounced in mid-continental regions, decline towards the coasts, and are sometimes reversed in maritime regions. The extremes of low temperature follow periods of maximum solar activity as indicated by the number of sun spots and the rapidity with which they are formed. The periods of heaviest rainfall follow those of lowest temperature at intervals of a few years. The other extremes are characterized by diminished solar activity followed by higher temperatures and, a little later, by scarcity of rainfall. The cycles have been traced back by Clough to about 300 A. D., but only the data of the last century can be accepted as approximately accurate. During that time, it may be noted, neither the extremes of heat nor of cold have shown any tendency to increase in intensity.

The Bruckner cycles appear to differ from those of the glacial periods only in degree and regularity. The effects upon glaciers, rivers and lakes are of precisely the same nature; and the distribution

of the two appears to be identical so far as the continents are concerned. Both are world-wide phenomena. The changes of climate which have been discussed above as found by Huntington to have taken place in Central Asia are, he claims, similar in nature to both the Bruckner and the glacial cycles, and lie between them in intensity. In his opinion it is reasonable to suppose that the three types of climatic change are of the same nature, are of the same solar origin, and are of equally wide distribution. This may be true, but he does not adduce sufficient evidence to justify the acceptance of these hypotheses, either as regards the nature or origin of his third type.

From the above précis of the work of Ellsworth Huntington it will be clear that an examination of historical, and perhaps prehistorical, data should yield further results.

Professor Myres, Wykeham professor of ancient history at Oxford, in an authoritative sketch of the dawn of history [3] remarks:

The Arabian desert is one of the earth's great reservoirs of men. Much of it, indeed, is usually uninhabitable; but its surface, gently sloping eastward till it dips into the Persian Gulf, is much more diversified than the Libyan desert by hollows which are moist enough for grass * * * When the supply of moisture is at its maximum, Arabia can therefore breed and support vast masses of pastoral folk, each with its wealth of sheep and goats, its rigid patriarchal society, its ill-defined orbit within which it claims first bite of the grass and first draught from the wells, which it believes its forefathers opened. But if moisture fails, as there seems reason to believe that it does from time to time, in large pulsations of climatic change, man and his flocks must either escape or perish. Fortunately, escape is easy; the tribes are always on the move; and the drought spreads but gradually.

In connection with the distribution of the Indo-European languages he says (p. 195):

Their wide geographical range, from our own islands to northern India, and from south Persia to Norway, is nevertheless limited enough to suggest that the whole group stands in somewhat the same relation to the northern grassland, as the Semitic languages to that of Arabia. Though the Indo-European languages differ far more widely from one another than even the most distinct among the Semitic group, they all possess a recognizable type of grammatical structure, and a small stock of words common to them all, for the numerals, family relationships, parts of the body, certain animals and plants * * * It is still generally believed, in spite of much discouraging experience in detail, that from this primitive vocabulary it is possible to discover something of the conditions of life in regions where a common ancestor of all these languages was spoken; and when we find it generally admitted, (1) that the domestic animals of this "Indo-European home" included the horse, cow, and pig, as well as sheep, goat, and dog, and that the cow was the most honored of all; (2) that these societies, though mainly pastoral, were not nomad, but had homes and some agriculture; that they used both plow and cart, had a considerable list of names for trees, and some experience of the simplest forms of trade; (3) that the social structure was patriarchal, and that the patriarchal households lived in large loosely federated groups under elected chiefs; we are probably not far wrong in regarding the first users of this

[3] The Dawn of History, p. 104. Home University Library (Butterworth, reprint 1927).

type of speech as having inhabited some part, perhaps many contiguous parts, of the parkland country which fringes these steppes, and as having spread in a long period of slow development; accelerated from time to time by drought, and migrations caused by drought. Some drifted in moister periods in the direction of the treeless steppe, losing or confusing their vocabulary for forestry and farming; others, in dry spells, further into the forests, with corresponding forgetfulness of their more pastoral habits. Much recent controversy over details would have been avoided if it had been realized earlier by students of these languages that the geographical régime of all grassland regions is liable to these periodic changes; and that the immediate effect of such change is either to alter the mode of life of the inhabitants till it suits their new surroundings, or else to drive them out into regions where they still can live in the ancestral way.

Professor Myres describes the grassland area to which he refers as consisting of two great reservoirs in hour-glass form, fringed by forest or desert, one extending for 1,500 miles from the Carpathians to Orenburg, the other for 1,000 miles from that point to the high ground of Elburz or of Tianshan. In northern and central Europe, where the rainfall is distributed fairly evenly throughout the year, grassland gives place to scrubland, and the latter passes into that deciduous forest which once reached without intermission from the Atlantic to beyond the Urals.

Ellsworth Huntington and Professor Myres have thus traced the connection between changes of climate and certain historical events. The propositions which they have established suggest a detailed analysis of the material dealing with historical events of this type. This analysis yields the following results:

In the centuries immediately preceding the year 2000 B. C. the first great movement of the steppe peoples foreshadowed the modern world. The Canaanites poured out of Arabia, and the Hyksos, the shepherd kings, crossed the mountain ranges through Persia and Palestine into Egypt.[4] The Hyksos brought the horse. It was previously unknown in Arabia and in Egypt. At this time Egypt, the Aegean, Mesopotamia, and southern Arabia were the centers of civilization.

Tartar nomads must have inhabited the steppes of Europe and Asia, and early users of the "Indo-European" speech the surrounding forest and parklands of the two continents. The Alpine race occupied the mountain zone from the Western Alps to the Pamirs; and the Mediterranean race, described by Professor Sergi, the shores of that sea. The Caspian Sea and all the lakes and marshes of Europe and Asia were larger than they are now, glaciers were more numerous and extended further into the valleys. The rainfall was generally heavier, and regions now steppe were then forest clad, while some tracts which are now desert provided good pasturage.

---

[4] The so-called Median Wall (from the Euphrates to the Tigris) was probably built at this period. Professor Myres states that it is certainly elder than the Median conquest, and that its object clearly was to keep out nomads.

The next great movement was one of agricultural as well as of nomadic peoples. Between 1600 and 1300 B. C. the Aramaean nomads from Arabia entered Mesopotamia, the Indo-European agriculturalists entered India and Persia, Indo-Europeans for the first time came into contact with Syria (witness the Tel-el-Amarna correspondence), the Hittites entered Asia Minor, the Achaeans settled in Greece. During this period and actually between 1400 and 1350 B. C., Minoan civilization suffered a devastating blow. It may be suggested that the Iron Age began in the Mediterranean somewhere about the fifteenth and fourteenth centuries B. C. It was probably introduced as a result of migrations from Europe north of the mountain zone.

A third important period of migration is dated between 1000 and 600 B. C. During these centuries the Celtic movements are traceable along the north of the mountain ranges from the Italian Alps to the shores of the Caspian. The Cimmerian section disturbed by pressure from the Scythians crossed into Asia Minor by Darbend. They or other migratory tribes were responsible for the disappearance of the Hittite State which had been a leading power for several centuries. The Dorians pressed into Greece and caused nearly three centuries of chaos there. The Medes overran Persia.

Shortly after 200 B. C. a fourth period of disturbance and migration began, when a tribe of nomads (probably Turki by race), known to the Chinese as the Hiung-nu, defeated the Yueh-chi, who occupied the Province of Kan-suh. The Yueh-chi in turn attacked and dispossessed the Saka, or Scythians, who then occupied the steppes north of the Jaxartes. The Yueh-chi began to settle in Bactria about 70 B. C., and the Saka passed on into India and settled in the Punjab, Kathiawar, and Gujerat. At the same time Persia was overrun by nomadic Turanians. Toward the end of the second century B. C., Germanic hordes threatened Gaul and Italy. Their advance was only stemmed, after special exertions, by the organized might of the Roman arms.

A fifth period, involving a most serious check to the growth of civilization south of the mountain zone, falls between 250 and 650 A. D. About 250 A. D. a series of catastrophes occurred in India, Greece, and Italy. The Kushan kingdoms in northern India and the Andhra dynasty in the south of the peninsula were extinguished as the result of barbarian migrations. Simultaneously, the Goths pressed into Greece and took Athens by storm. Their inroads continued in spite of a crushing defeat in 269 A. D.

All along its frontiers the Roman Empire was hard-pressed during the latter half of the third century. Franks and Alemanni roamed through Gaul, Saxons plundered the coasts. A hundred years later a stream of Huns, separating from that which filled the valley of the Oxus and later overflowed into Persia and India, poured into eastern Europe (about 375 A. D.) driving the Goths to the south of the Danube

and displacing the tribes in Germany. The Roman Empire was divided in 395 A. D. The Goths were settled in Moesia about 390 A. D. The Western Empire succumbed to the Germans, who after inundating Gaul, Britain, Spain, and the North African Province seized the imperial diadem in 476 A. D. The Hunnish Empire in Europe was broken up about 460 A. D. by fresh swarms of immigrants from Asia.

Almost in the same year the Huns poured into India and overwhelmed the kingdoms of the north. About 456 A. D. the Sassanian dynasty of Persia built the walls at Darbend and at Aboskun (mentioned already as now being below the level of the Caspian) as a defence against the nomads. They were able by this means to avoid their fate for a time, but by 484 A. D. all resistance had ceased.

The sixth and last period is that of the eleventh, twelfth, and thirteenth centuries, in the first of which the "wild Magyar horsemen" were restless in Europe. During the thirteenth century swarm after swarm of Mongols poured into Europe and into India.

The dates marking the duration of the fourth, fifth, and sixth of these periods are matters of exact historical record. Those of the first, second, and third are fixed less finally by historical evidence, by tradition, and as a result of archeological investigation in both continents and in Egypt and the Aegean. Each period lasted from about three to nearly four centuries; and the intervening periods were of a similar duration. During the intervening periods civilized and organized states were developed in some or all of the regions south of the mountain zone.

Between the first and second migratory periods the Theban dynasties reorganized Egypt and founded the "New Empire." Minoan civilization dominated the Aegean. The Canaanites settled down in prosperous communities in Palestine and Syria, and the Assyrian power grew steadily in Mesopotamia.

Between the second and third periods the Aryans developed the Vedic civilization of India, the Hittite state grew up in Asia Minor. Egypt, Judea, and Mesopotamia were all prosperous. This was the Achaean age of Homer.

After the third migratory period civilization burst suddenly into full flower along the southern slopes of the mountain chain, in India, in Persia, in Asia Minor, in Greece, and in Italy. In each case it occurred after a fusion of the "Aryan" or "Indo-European," races with the earlier inhabitants and in a climate suitable to agriculture and to a "high stage of development of the Indo-European."

After the fourth migratory period India, Persia, and Greece suffered a relative decline, and Italy was preeminently the center of civilization. The countries north of the mountain zone were beginning to develop under Roman influence.

After the fifth, most disastrous period, modern Europe begins to emerge from the chaos of the Dark Ages. After the sixth and last irruption from the steppes the Renaissance ushers in the present age.

Taking the periods after 600 B. C. as being more precisely dated, it is clear that each complete climatic cycle had an average duration of approximately 640 years. The years 1170 A. D., 530 A. D., and 100 B. C. indicate the crests of the waves of migration and drought. Proceeding further back, if the same figure held good the next three crests would be represented by the years 750 B. C., 1390 B. C., and 2030 B. C.; and these dates accord with the general estimate of the duration of the first three migratory periods as indicated in previous paragraphs. It may, therefore, be inferred for the present that these dates provide a measuring rod for the history of the 2,500 years preceding our era. An attempt has been made to represent the historical movements in graph D on page 432.

An analysis of physiographic and of historical data leads then to the following conclusions:

(1) A regular succession of climatic cycles approximately 640 years in duration, each including on the average something like 300 years of increasing aridity, has produced a series of alternating periods of migration and consolidation in Europe and Asia, where the effects can be traced between the years 2300 B. C. and 1600 A. D.

(2) These periods of migration have also been periods of internal decay in civilized states and among settled communities. This would, a priori, be expected to result from unsettled and particularly deteriorating conditions of climate causing deterioration in the agricultural and commercial conditions under which the people of such communities lived.

It may be deduced that the periods of consolidation would necessarily be such that conditions were relatively "settled" in every respect; that is to say, when at the most very slight variations of climate occurred.

(3) Physiographic conditions generally (c. f. the graph and other evidence relating to the levels of the Caspian Sea) prove that, taking the period of the last 7000 years as a whole, there has been a large-scale but very gradual tendency towards desiccation.

From this it may be inferred that the 300-year periods of migration have been of such a nature that this general primary tendency has been accelerated by secondary conditions, and that the 300-year periods of consolidation have been of such a nature that the corresponding secondary conditions have served more or less closely to counteract this general tendency.

This general tendency is reflected in history by a tendency for the centers of civilization to move gradually away from the equator. Prior to 1000 B. C. conditions were most favorable to physical and

intellectual well-being in the region of the thirtieth degree of latitude (Egypt and Babylonia); from 600 to 300 B. C. between the thirty-fifth and fortieth degrees (Greece); from 300 B. C. to 400 A. D. between the

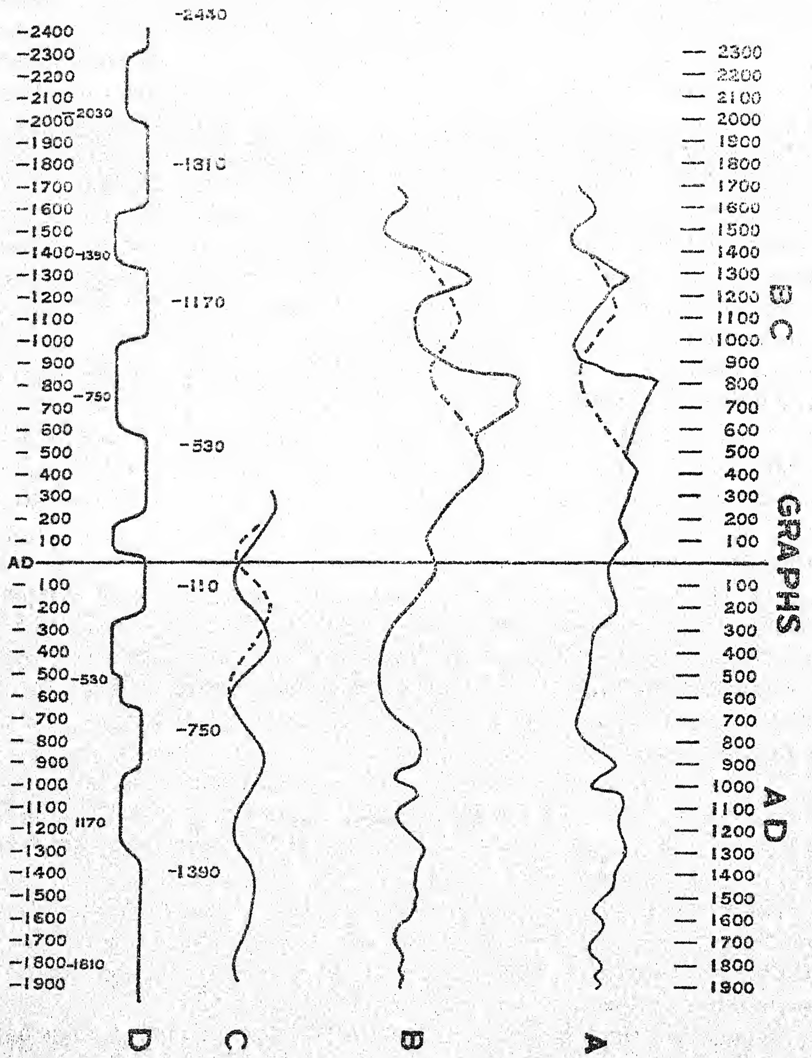


Figure 2.—A, From Brooks' "Eurasia," Figure 38, in Climate Through the Ages. B, From Brooks' "Western Asia," Figure 35, in Climate Through the Ages. (A and B by permission of the author and Messrs. Ernest Benn, Ltd.) C, Pearson's graph from the Geological Magazine, 1901. D, Graph representing historical fluctuations; the "crest" line represents periods of stability and settlement, and the "trough" line periods of disturbance and migration. In A, B, and C the dotted lines are inserted to indicate the divergence of Brooks' and Pearson's graphs from the 640-year cycles

fortieth and forty-fifth degrees (Rome); from 800 to 100 A. D. between the forty-fifth and fiftieth degrees (France and northern Italy); and finally after 1000 A. D. between the fiftieth and fifty-fifth

degrees (England, northern France and Germany). After 400 A. D. no clearly defined distinction can be made. Italy, Spain, France, England and Germany can all claim to have been pre-eminent in different ways at different times; but the general tendency for the best conditions to move northwards is undeniable.

The year 1840 should have marked a wave crest of migration, of desiccation, and of a low level of the Caspian Sea. A marked drop in this level did occur about 1820, but it was evidently not connected with any cause sufficient to bring about disaster in the steppes or a very serious economic upheaval. From the generally "settled" conditions of the last 200 years it follows that either the primary or the secondary cause of desiccation, or both, have ceased to exercise their former influence.

Following Huntington's conclusion that the changes which now appear as 640-year cycles lie midway between Bruckner's and the glacial cycles in intensity, the causes of change referred to above as primary must be regarded as being connected with the last glacial cycle.[5]

The geographical and historical evidence in favor of the existence of a 640-year cycle is inconclusive and incomplete in the absence of any explanation of its cause or causes. The alternating periods of migration and consolidation are, however, so clearly marked that their existence can hardly be a matter of controversy, apart from the question of periodicity. The connection between droughts and migrations has been recently discussed both by H. Peake and C. E. P. Brooks. Their work shows that there is need for the treatment in greater detail of the historical evidence, both as regards the migrations of the steppe peoples and deterioration in the more highly organized states.

The fact that conditions have been so settled for nearly 600 years, (since the migrations of the Mongol period), has led to these questions being regarded as of academic or even merely "bookish" interest. It is, however, possible that changes may occur again on a scale similar to those which destroyed the civilizations of the past. Some such change as that which brought new peoples into Italy, Greece, Asia Minor, Mesopotamia, Persia, and India between 1600 B. C. and 1300 B. C. might again take place suddenly and transform the world in the life-time of our own or the next generation. Such considerations indicate that these questions, being, at least, of potential importance in high politics, deserve greater attention than they have

[5] Other evidence bearing on the nature of these primary and secondary causes of change is, possibly, to be found in such facts as that the level of the Caspian was much lower during the fifth drought than it is now: that this drought, judging by the historical evidence, appears to present a triple wave crest: that the fourth and sixth droughts had much less serious effects than the third and fifth: and that the effects of the later droughts were comparatively unimportant in Arabia.

received. If man is to be master of his destiny, to "live well", and "to conquer nature by observance of her laws", these are the secrets which he has now to learn.

The problem at this moment seems to offer two main lines of attack—to find the causes of the alternate (300-year) periods of migration and consolidation, and to determine the chronology and causes of the glacial periods. Both solutions are for the present veiled in obscurity.

The conclusions so far reached suggest an examination of all phenomena likely to be related throughout the whole field of scientific inquiry, and primarily in those branches of knowledge classified as geology and meteorology.

In the sciences concerned with the study of past events, in geology, paleo-climatology and archeology, as in history, a clear arrangement of the facts is impossible without a standard for the measurement of time. The need for such a standard has long been felt by geologists. Nearly a century ago they sought the aid of the astronomers in an attempt to give definition to geological time. No solution has been found on those lines. In Climate Through the Ages, Brooks elucidates many of the phenomena connected with the great glaciations, but he shows that questions of chronology are still in doubt. One possible factor in the equation, which is still unknown in spite of observations dating from Ptolemy's time, is the variation in the obliquity of the ecliptic. If more were known about the periods, extent, and nature of this variation, and its exact relation, if any, to changes of climate, we should be nearer a solution of the questions connected with the passing of the last glaciation, and the progress from paleolithic to neolithic civilization which accompanied it. Assuming that the "primary tendency" for civilization to move away from the equator is connected with the glacial cycle, we should be nearer to understanding whether and when the centers of civilization are likely to pass south again.

Similarly it is tempting to hope that the inference of a 640-year cycle may be supplemented by evidence as to its origin. If it were established, it would facilitate the study of future, as well as of archeological, problems.

Whether this inference of a regular periodicity is true or not, the fact of the occurrence of long periods of drought and disturbance on the one hand, and of climatically and economically "settled" conditions on the other is susceptible of scientific explanation. The problem will be solved eventually, if only because a knowledge of all the factors will make it possible to foresee and provide for future catastrophes.

The main factors as known at present appear to be variations in the position and intensity of the north temperate storm belt and in

the direction taken by depressions as they move eastwards across Europe and Asia. According to Brooks it has been found that the area in which annual rainfall variations have a positive correlation extends only a short distance north and south, but for many hundreds of miles across Europe into Asia. This is the area whose rainfall influences the migrations from the Steppes. Ellsworth Huntington has partially established correlation with other parts of the world, but the evidence in that respect is not yet complete. In view of recent work proving, among other things, relations between variations in the Indian monsoon and rainfall in Africa and South America, it seems probable that factors sufficiently powerful to cause the great droughts on the Steppes could not but be world-wide in their effects. Huntington has suggested a gradual northward movement of the storm belt corresponding with, and connected with, the movement of civilization in the same direction.

H. W. Pearson, in the *Geological Magazine*, 1901, suggested that the evidence of the raised beaches proved the existence of a regular cycle of oscillations of sea level. He considered that this cycle had had a period of 640 years in recent times, and one of 500 years about the time of the Christian era. He appears to have connected these oscillations—perhaps as a guess, for he gives no reasons—with the swing of the magnetic needle. If his theory is correct it would appear to involve the synchronization of increasing glaciation at the poles with scanty rainfall on the steppes, and vice versa. The evidence has not been fully examined. The position is thus obscure; but the time seems ripe for fresh discoveries.

When so many guesses have been made perhaps one more may be permitted. It is generally felt that there is something lacking in the Darwinian view of the origin (and extinction) of species, and that some simple explanation may have been overlooked. Is this not because the problem is considered as if environment were not constantly changing all over the world? The evidence now under consideration shows that from time to time forest areas become steppe, and steppe areas desert, and vice versa. Where an area of one kind is, as it were, an "island" surrounded by areas of other kinds, slight changes of climate may lead to the extinction within that area of a species, and consequently, where the change of climate persists, to the permanent modification of another species which had partially depended on it for subsistence.

Change and response to change provide the setting of the greatest of all dramas, the drama of man's ascent toward the crisis where, in virtue of his intellect, he seeks to master those natural forces to which he once attributed divinity.

82322—30——29

UR OF THE CHALDEES: MORE ROYAL TOMBS [1]

By C. Leonard Woolley

[With 17 plates]

STRATIFICATION

The first month of our new season at Ur has not indeed produced treasures to eclipse those of last winter, when we discovered the tombs of the ancient kings with their wealth of gold and their array of human victims, but it has brought us, together with many objects of first-class importance, more information about the ritual of those royal funerals.

All over the cemetery the upper levels have been disturbed by the grave diggers of a later period and in half of the area worked by us during November grave robbers, house builders, and layers of drains had made havoc of the site, but in the other half conditions were simpler and it was possible to observe as never before the vertical relations between successive strata; factors which elsewhere had vanished altogether or survived only as isolated and meaningless fragments we could here connect into a scheme. Here the evidence of the whole strongly corroborates the chronological scheme suggested by me two years ago; the Sargonid graves are clearly distinguished by the types of pottery and weapons, etc., the first dynasty graves come close to these in level and have often been disturbed by them, and then after a comparatively barren stratum come those of the early series with their distinctive furniture. Certain modifications of my previous arguments are enforced by observations made under better conditions, but the main thesis seems to hold good.

One grave which I would assign to the latter part of the early period contained an object of very great value for comparative dating—a complete painted clay vase of the later Jemdet Nasr type. This is the only example of this ware yet encountered by us. It must be an importation at a time when Sumerian pottery was exclusively monochrome and it appears to support the view I have

[1] Reprinted by permission from The Museum Journal, Museum of the University of Pennsylvania, March, 1929.

already put forward that the Jemdet Nasr ware is northern and Akkadian, not Sumerian, and that in the north its manufacture continued until the native Akkadian culture had been swamped by the Sumerian, i. e., until the rise of the first dynasty of Erech if not until that of the first dynasty of Ur. At any rate it must mean that the Jemdet Nasr culture, though earlier, is not much earlier that that of our first series of graves.

FIRST SHAFT: DEATH PIT WITH 40 BODIES

Last year we recovered the ground plan of a king's grave; this year we have traced the sections of such graves and they are hardly less illuminating. The first clue was given by the discovery, not very deep down, of a layer of reeds extending up to the mud brick walls of what seemed to be a small room. The reeds were removed and under them, crushed to fragments by the weight of the soil, were innumerable clay pots, animal bones, and several human skeletons, all lying on a floor of beaten clay. It was easy to recognize that these things had been buried from the outset, were in fact an underground votive deposit, and that the building which contained them was a subterranean building; closer examination showed behind the walls an earth face cut at a gentle slope, so that the building lay in a vertical shaft. The theory arose that at the bottom of that shaft there would be a royal tomb and that when the king had been buried and his retainers duly slaughtered around him and the earth thrown back above their bodies then at intervals votive offerings would be laid in with the earth and at a certain stage the filling in of the shaft would be stopped and a chamber or chambers would be constructed in it to receive the last offerings; then more earth would be poured in and perhaps a superstructure in the form of a funerary chapel would complete the whole. So much for the theory; in fact we have dug down some 20 feet below the layer of pots, finding every now and then a fresh group of offerings or a subsidiary burial, and at the bottom we have found not indeed the tomb chamber of the king, which must lie under the mass of soil not yet excavated, but the "death pit" inseparable from it; in this open part of the shaft measuring less than 20 feet by 10, there are crowded, more or less in ordered rows, the bodies of 39 women and 1 man.

SECOND SHAFT: SEAL OF MES-KALAM-DUG

Another shaft opened more sensationally with a wooden box in which were two daggers with gold blades and gold-studded handles and a cylinder seal inscribed "Mes-kalam-dug the King," a relative, one must suppose, of that prince Mes-kalam-dug whose gold helmet was the glory of our last season. As the previous grave has produced the seal of a woman bearing the title "Dam-kalam-dug"—"the

wife of the good land"—it must be supposed that "kalam-dug" is part either of a title or of a family name. Immediately below this came a coffin burial with stone and copper vessels and a mass of clay vessels extending over the whole brick building which was now found to occupy the pit; then more layers of votive pots and more subsidiary burials, all separated by floors of beaten clay or by strata of clean earth. There followed a long blank which made us fear that we might have lost the clue, but the shaft continued; in opposite corners of it there appeared heaps of wood ash and, lower down, clay cooking pots and animal bones, the relics of a funeral feast or sacrifice made in the pit itself. The reason for the fires being precisely at the level at which they were found soon became obvious, for half way between them were found lumps of limestone set in clay mortar which spread outwards and downwards until from a border of carefully smoothed clay there rose intact the stone roof of a domed subterranean chamber, corbel-built of limestone rubble set in clay mortar; a little above the springers, holes through the masonry containing remains of wood showed that a solid centering had been employed for the construction of the central part of the dome, the stones being laid in position over a heap of light earth and straw carried by beams and matting. On the flat space round the dome funeral fires had been lit and had burnt for some time before the shaft was filled in for the construction of the subterranean building higher up. With the ashes of the fire were mixed animal bones.

The domed building had been constructed at one end of a pit dug at the bottom of the main shaft, three of its walls being against the pit's sides and one, in which was the door, open to the court reserved in the prolongation of the shaft; this door had been blocked with large stones. Apart from a certain amount of natural subsidence, walls, dome, and door were intact, though the latter was very difficult to detect, so closely did its blocking resemble the rough wall face, while the shifting of stones had disguised the outlines of the doorway. Through the beam holes it was possible to see that the floor was covered with some object of paneled wood, through the decayed remains of which protruded several large copper vessels and one of gold.

Considering how elaborate the tomb structure was, the contents were simple. Below the woodwork, which seems to have been a canopy, there lay six bodies of which four were servants or soldiers, men distinguished only by the wearing of copper daggers, and one apparently a maid servant; the sixth body, laid out in the center, was that of a woman wearing a wreath of gold beech leaves and another of ring pendants strung on carnelians, gold earrings, finger rings, necklaces of gold and carnelian, gold hair ribbons, and a frontlet decorated with a star rosette and secured by long gold wires; on the

breast was a carnelian-headed gold pin of the bent type not hitherto found in precious metal, and a gold cylinder seal having two registers of design in one of which is shown a banquet and in the other musicians playing on harps and other instruments; by the hands was a fluted gold tumbler much like that found in Queen Shub-ad's grave but not quite equal to it in quality. The bodies rested on a floor of mud bricks and smooth clay; this was curved so as to present the appearance of a vault and gave out a hollow sound when hit; it was therefore lifted, and below it was found a stratum of broken pottery and a very large vertical drain, which, however, only went down some 50 centimeters into the soil; below it there seemed to be the original débris in which the early graves are dug. The excavation of the tomb is not finished, as the court in front of the door of the domed chamber has yet to be cleared: Further work should throw more light upon what are the most completely preserved though not the richest of the royal graves, but already we have evidence of a much more complicated ritual than could be deduced from last year's results.

PRIVATE GRAVES

Of the private graves one of the best was that of a very young child perhaps 3 or 4 years old. Besides a set of stone vases the little shaft contained a group of miniature vessels in silver and on the body were miniature gold pins, while on the head was a miniature wreath of gold beech leaves, another of gold rings, and one with pendants of gold, lapis, and carnelian. Another child's grave contained a fine head ornament, a chain of triple beads in gold, lapis, and carnelian, with a large gold roundel of cloisonné work and two others of wire filigree. A woman's grave produced, together with many other objects, the remains of a harp similar in type to that of Queen Shub-ad though simpler in character, in that it had no animal's head and was decorated with silver instead of gold; a very important feature was that the woman wore on her head, as well as the normal beech leaf and ring wreaths, a diadem decorated as was the second diadem of Queen Shub-ad, with pomegranates and figures of animals in gold over a bitumen core; the workmanship is much inferior, but the parallel is very striking.

A very interesting discovery was that of another harp. Two holes in the soil were noticed by a workman and after examination were filled by me with plaster; the earth was then cut away and more plaster work was done where the decay of woodwork had left hollows. The result was a complete cast of a wooden harp decorated with a copper head of a bull. Further clearing exposed the remains of the actual gut strings, mere hairlines of fibrous white dust but, even in the photograph, perfectly clear as the 10 strings of the instrument. It was the more interesting as this is a harp not of the type of that

found in Shub-ad's grave but resembling those figured on the shell plaque from the gold bull's head found last year and on the "standard," having the strings attached by tying (not by metal keys) to a horizontal beam.

The grave with the ruined harp of the type of Shub-ad's also produced a silver bowl, unfortunately in very bad condition, decorated with a design of wild goats in repoussé work walking over mountains represented in the conventional way by engraved lines; this is the first example that we have found of this technique in silver. Another technical novelty was given by the imprint on mud of a piece of wooden furniture, itself completely decayed, decorated with engraved designs (the engraved lines filled with color as in the case of shell plagues) and with carving in low relief; the possibility of ever finding the actual wooden objects preserved is so small that evidence of their character is the more interesting.

An alabaster lamp with a figure of a man-headed bull carved in relief on its base shows a variant from the type given by a similar but later lamp found last season. Perhaps our best object is a copper sculpture in the round of a human head with bull's ears and horns, probably a unique piece; this was found loose in the soil, not associated with any grave, and its use is also uncertain.

THIRD SHAFT: HARPS AND RAM STATUES

In one part of the work there had been for a long time signs which seemed to portend a royal tomb and at last the pickmen detected the shelving sides of an ancient pit-shaft. As the filling of this was removed we found that only one end of the shaft lay within the area at present being cleared, the rest ran on under the 25 feet of earth where as yet no digging had been done, so that for the moment we could clear no more than a section of a shaft whose total area must remain unknown. The rim of a very large copper vessel was the first thing to be found, then another appeared next to it, and then the black stain of decayed wood; very careful clearing laid bare the wheels of a wagon, a perfect impression of a thing which had itself long since vanished, but on the soil could be distinctly seen the grain of the different planks of which the wheel was made, the curve of the rim and the stump of the axle; in front of it, in the part which we could excavate, lay the skeletons of two asses and a groom and amongst the bones the line of silver and lapis lazuli beads which had decorated the reins; it was just such a wagon as we had found in the king's grave last season.

The mud floor on which the wagon stood had been covered with matting and toward the sides of the shaft this rose steeply up as if in the center it had sunk beneath the weight of the wagon and its team. That could only have happened if the soil beneath them was

soft and had recently been disturbed, so we dug down by the side of them and discovered some three feet below, the skeletons of other animals, sheep and cattle, a collection of copper vases and weapons, and the bones of a man. Here was a novel feature; the bodies of the victims and the offerings had been placed in the grave pit, earth had been heaped above them and stamped down and mats laid over the top, and thereafter the wagon had been driven in and the slaughter of beasts and of grooms had been a later act in the burial tragedy.

It was probable that the wagon stood immediately in front of the entrance to the shaft, so digging was continued behind it and the sloping earth side was traced back for some distance; but to our surprise this proved to be the side not of a narrow passage ramp but of a pit some 25 feet square, a "death pit" larger than any we have yet encountered, and the whole of this is covered with the bodies of human victims laid out in ordered rows. For more than a week we have been at work clearing the last 9 inches or a foot that covered the floor of the shaft and a third of the space still remains to be examined, but already we have listed 45 bodies, of which 39 are women and 6 are doubtful. And the riches of them are astonishing. In the king's grave last year we found nine court ladies wearing headdresses of gold and semiprecious stones; here there are already 34 such, and for the most part far more splendid—the best only less remarkable than the headdress of Queen Shub-ad herself, gold hair ribbons, wreaths of gold leaves and flowers of colored inlay, pins of silver or gold, necklaces of gold and lapis row upon row, a wonderful group of regalia. Nor are these all the contents of the pit. In one corner there lay folded up on the top of the bodies a sort of canopy whose ridgepole was decorated with bands of gold and colored mosaic over silver and the uprights were of silver with copper heads in the form of spear points hafted with gold, while shell rings held up the hangings. In another corner were harps. Of one the sounding box was decorated with broad bands of mosaic, the upright beams encrusted with shell, lapis lazuli, and red stone between bands of gold, the top bar plated with silver; in front of the sounding box was a magnificent head of a bearded bull in gold and below this shell plaques with designs picked out in red and black. A second instrument of the same type was entirely in silver relieved only by a simple inlay in white and blue and by the shell plaques beneath the silver cow's head in front of the sounding box. Below these was found a third harp of a different sort; the body, made of silver, was shaped rather like a boat with a high stern to form the back upright; the front upright was supported by a silver statue of a stag nearly 2 feet high whose front feet rest in a crook of the stem of a plant, made of copper, the long arrowlike leaves of which rise up on each side level with the horns. An exactly similar figure of a stag but made of copper and mounted on a square copper base lay alongside.

Possibly it was the decoration of yet a fourth harp the body and uprights of which had been of wood, now decayed; unfortunately the copper too was terribly perished, and though we succeeded in lifting it, it can never be more than the wreckage of itself, whereas the silver animals, though crushed, are on the whole very well preserved.

Another corner of the pit yielded two objects absolutely unique in our experience—a pair of statues in the round of rampant rams. The heads and legs of the beasts are of gold, the horns and the long hair over the shoulders are of lapis lazuli, and the fleece over the rest of the body is of white shell, each tuft carved separately; the belly is of silver. The animal is reared right up on its hind legs, so standing 20 inches high. On either side of it are tall plants whose stems, leaves, and large rosettelike flowers are of gold, and to the stems of these the front legs of the ram are tied with silver bands. The composition is precisely that to which we have been accustomed by the engravings on shell plaques, but here we have it executed in the round, on a large scale and in precious materials; the workmanship is admirable and the color scheme is most striking. Baroque as they are, these gay statues seem to be rather of the school of Benvenuto than products of early Sumerian art as we should have imagined it. It should be added that they are to be judged not as free art but applied, for a socket above the shoulders of each ram shows that they were really the supports for some article of furniture or ornament which has disappeared, leaving no more trace of itself; whatever it was, it was a very gorgeous object.

The "death pit" has still to be cleared of its remaining gold. In the meantime we are digging down from the modern surface in the hopes of finding beneath it the actual tomb to which this should be the introduction.

THE GREAT STONE TOMB

With the clearing of the "death pit" we finished up the area selected for the first stage of our season's dig. The number of graves dug this season already exceeds 350, and the small objects from them have been excellent. Starting on a fresh section of the graveyard we obtained from the outset a piece of interesting information. Below the mud-brick Temenos Wall of Nebuchadnezzar, which we had to cut away, there lay private houses of the little known Kassite period (ca. 1700–1200 B. C.), proving that Nebuchadnezzar did not simply follow tradition but enlarged the sacred area of the city, probably so as to include new temples of his own founding. These buildings, and the brick tombs which lay beneath their floors, had disturbed the upper levels of the older cemetery, but in spite of this the ordinary graves of the Sargonid age (c. 2700 B. C.) produced, as we dug deeper, their accustomed harvest of gold and silver ornaments, stone vases, and copper weapons, and those of the first dynasty of Ur, 500 years older and lying lower down in the soil, were not less rich. Much

more important was a royal tomb which underlay the rest. It was a single building measuring 42 feet by 26, built throughout of unhewn limestone; it contained four chambers, two small central rooms roofed with ring domes and two long flanking rooms with corbel vaults, all communicating with each other by arched doorways: Inside, the roughness of the walls was disguised by a smooth cement plaster, and the same plaster was used for the floors. The tomb is indeed an underground house, and this fact throws new light on the beliefs of the oldest Sumerians and should explain why the dead king was accompanied by such a crowd of courtiers and domestics—his life was to continue in surroundings as like as might be to those of this world. Of the servants and court attendants there remained in this case little but scattered bones, for ages ago robbers had broken through the roof of the tomb and made a clean sweep of its contents. Some of the necklaces torn from the bodies had broken, and the floors were littered with lapis lazuli and gold beads, two silver lamps lay overlooked in a corner, there was a broken sceptre of mosaic work with gold bands decorated with figures in relief; but the great treasures which the tomb must have contained had vanished. It was a disappointment of course, but we had the satisfaction of having found the tomb itself, a first-class monument of this early age. How much the robbers had actually taken one can only guess, for not all the royal graves were as rich as Queen Shub-ad's; we have just laid bare one "death pit" in which the ranked bodies were all quite poorly attired, with a few silver ornaments in the place of gold; but the pit rewarded us well, for against its edge stood a harp with a particularly fine calf's head modeled in copper and on the front of the sounding box a panel of mosaic work with human figures in shell set against a background of lapis lazuli, the technique of the wonderful "standard" discovered last season.

DEEPER LEVEL AND OLDEST TABLETS

Here, too, another discovery was made. The graves are all dug down into a vast rubbish heap which sloped down from the walls of the earliest Sumerian settlement to the marsh or river out of which it rose, and the bottom of this particular "death pit" just touched a stratum of rubbish, necessarily very much older than itself, wherein lay multitudinous nodules of dark-colored clay; many were shapeless, but amongst them were written tablets and clay jar-stoppers bearing the impressions of archaic seals. Not so old as the pictographic tablets of Kish, which we may expect to parallel from the deeper rubbish strata of Ur, these documents carry us back to a period in the city's existence not yet illustrated by any other class of objects except crude figurines in clay of animals and men from which it would have been impossible to deduce the level of culture attained at the time.

LIMITS OF THE CEMETERY: THE PREHISTORIC CITY

The excavation of the ancient cemetery came to an end early in February and it was characteristic of the site that the very last grave discovered should be the richest of its period yet brought to light. It was of the Sargonid age, about 2650 B. C., and was that of a man, judging from the number of copper weapons placed at the head and along the side of the wooden coffin in which were the crumbling bones; amongst them were three of the largest spears that the cemetery had produced and with them a number of copper vessels, some unusually large, and a copper tray made to imitate basket-work and piled with bowls and vases of novel forms. Six gold fillets adorned the head of the man and round his neck were three strings of beads of gold and colored stone, agate, carnelian, jasper, chalcedony, and sard, stones which are rarely found before the time of Sargon of Akkad. On the wrists were four heavy bangles of gold and four of silver, and on the fingers were gold rings; by these lay two engraved cylinder seals of lapis lazuli capped with gold, and from one of the strings of beads hung a gold amulet in the form of a standing goat exquisitely modeled in the round, a real gem of miniature sculpture.

Having exhausted the graves in the area selected for this season's work we proceeded to dig down beneath them for relics of the older civilization represented by the great rubbish heaps in which the graves are set. In a stratum of this rubbish which is late in comparison with much that lies beneath it but very much earlier than the oldest graves, we were fortunate enough to find in a ruined house (for at one time the primitive settlement overflowed its normal limits and houses were constructed on the slope of the town's refuse dump) some 200 tablets written in a very archaic script, one of the oldest forms of writing known in Mesopotamia.

Meanwhile work on the other side of the excavated area proved the northwest limits of the cemetery also. Our work here produced no graves but either stratified rubbish or superimposed house remains according as the limits of the early town fluctuated in times of greater or less expansion. Near the surface we came on a pavement of plano-convex bricks which could be dated as not later than 3000 B. C. and we dug down through successive floor levels to a depth of 8 meters below this, by which time we were finding very early seal impressions on clay and pottery, painted or otherwise decorated, of types elsewhere occurring only below the 10-foot bed of clay which I have regarded as a relic of the flood. For the full working out of the earliest history of Ur excavations on a large scale ought to be undertaken either at this spot or a little to the northwest of it.

With regard to the ancient cemetery lying on the slope below the walls of the settlement, we now know its width and further excava-

tion of its length in either direction (probably little remains to be done to the northeast) can be carried on economically and with proper knowledge.

THE WALLS OF UR

Thoroughly to work out this prehistoric site was a task far too big to be tackled at the close of a season. Content for the moment with the very important preliminary results which we had obtained, we turned our attention during the last 10 days to the city wall, again with the idea not of complete excavation but of securing information which would enable us to draw up programs for future digging. The results were immediate and surprising.

The spot chosen was on the northeast side, just behind the expe dition house.

Two days' work sufficed to produce the real town wall which has a total width of more than 28 meters and is still standing more than 8 meters high. We were able in the few days that remained of the season to follow it in both directions for a distance of over a hundred meters and to establish something of its character and history.

Apart from a few literary references to its building and destruction we knew nothing about the wall. More than this, very little is known at all about Sumerian defenses, seeing that no expedition has yet undertaken the heavy task of clearing the circuit of an ancient town.

At Ur, the center of the site is surrounded by a ring of mounds, not continuous, for whereas in some parts they stand high and present on the outside an abruptly sloping face, in others they sink to the level of the plain or are so confused by adjoining mounds as to lose all character. But even from the ground something in the nature of an outline to the inner city detaches itself from the tangle of slopes and hillocks, and an air photograph shows much more clearly what can only be the defenses of the town. The inclosure is an irregular oval about three-quarters of a mile long by half a mile wide; outside it the suburbs stretch for miles, inside it, like the citadel inside the bailey, lies the sacred area wherein most of our excavation has been done; within the inclosure levels average higher than outside and it is reasonable to suppose that it represents the oldest settlement; certainly it remained throughout history the administrative and religious center.

The fortifications of the city were, naturally enough, repaired or reorganized a number of times; the earliest work that we have found dates to the third dynasty of Ur and is probably due to the founder of the dynasty, Ur-Engur (2300 B. C.), who explicitly claims its construction; we have reconstructions and additions by kings of Larsa (circ. 2000 B. C.), by Kuri-Galzu of Babylon (1400 B. C.), and by a later king whom we have not yet identified. Ur-Engur's wall

seems to have consisted of two parts, a lower wall of crude mud brick and an upper wall of burnt brick of which, in the section cleared by us, nothing at all remains. But the mud-brick wall is an amazing structure. It stood some 26 feet high, its back vertical, its outer face sloped back at an angle of 45 degrees, and at its base it measured not less than 75 feet in thickness! Really it served the purpose of an earth rampart along the top of which ran the wall proper, but it was itself built entirely of bricks carefully laid. Behind it the floor level was raised about 12 feet above that of the plain outside, though whether this was continuous over the city area or was in the nature of a platform backed against the wall we can not yet say; judging from surface indications the former would seem to be the case. The sloped mud face of the wall must have suffered badly from weather and it was twice reinforced with revetments which added another 18 feet to the wall's thickness; the authorship of these is still uncertain, but the first addition may well have been due to the Larsa kings, part of whose superstructure is well preserved. In their time the levels inside the wall had risen almost to the top of Ur-Engur's mud brick. So far as the inner face of this showed, they revetted it with burnt brick and set up along the top of it a continuous row of buildings which served a double purpose; they were at once the burnt-brick wall crowning the rampart and living accommodations for citizens or officials, for their inner ground plan is exactly that of the private houses excavated by us on the other side of the Temenos; in spite of their position and the fact that they are built to a general plan with bricks bearing royal stamps, there is nothing military about them. One is reminded of Rahab who dwelt upon the wall of Jericho and of some medieval city like Aleppo where the solid masonry of the ramparts rises up to merge insensibly into the flimsy window-broken backs of private houses.

We know that after a revolt against Babylon the "great walls of Ur" were destroyed by Hammurabi's son in about 1870 B. C. Then, and in the course of the next 450 years, even the lines of the superstructure must have vanished, for we find a great gate passage of Kuri-Galzu running athwart everything. It was strongly built with burnt bricks, a large proportion of which bear his name, but everything else of his work has been destroyed by a later building, a fort lying inside the wall and probably (though our work has not gone far enough to prove this) flanking one of the city gates. Only the mud-brick substructures of this are left together with the burnt-brick facing of its outer wall on the northeast, but the foundations show that it was extraordinarily massive, even the inner walls being never less than 13 feet thick. Notwithstanding this it appears to have been considered insufficient for the city's safety, for close to it on the northeast, just outside the lines of the old wall, we have exposed the greater part of a second external fort obviously of the same date

though also of unknown authorship. It is a rectangle with double gateways leading to a central court; the walls of burnt brick are over 20 feet thick; it seems to be such a tower as we might expect to find guarding the entry to the town.

Under the floors of the Larsa superstructure there were many tombs of the period, and later graves, mostly of Neo-Babylonian date, were found higher up; these produced a good deal of glazed pottery and a few other objects. From one room we recovered a collection of tablets, apparently business documents in envelopes, of Larsa date; the packing of a drain yielded an unusual object in the form of a fragment of a large stone jar bearing an inscription of Dungi; and in the foundations of the late fort was found a small female head carved in the round from gray stone, with inlaid eyes, very much in the style of the marble head with inlaid eyes discovered three years ago, but smaller and not quite so good.

If we clear the whole circuit of the walled town, as we ought to do, we shall not only have a very wonderful monument—our present work shows that—but for the first time we shall obtain an adequate picture of the system of military defence employed by the great builders of Sumer.

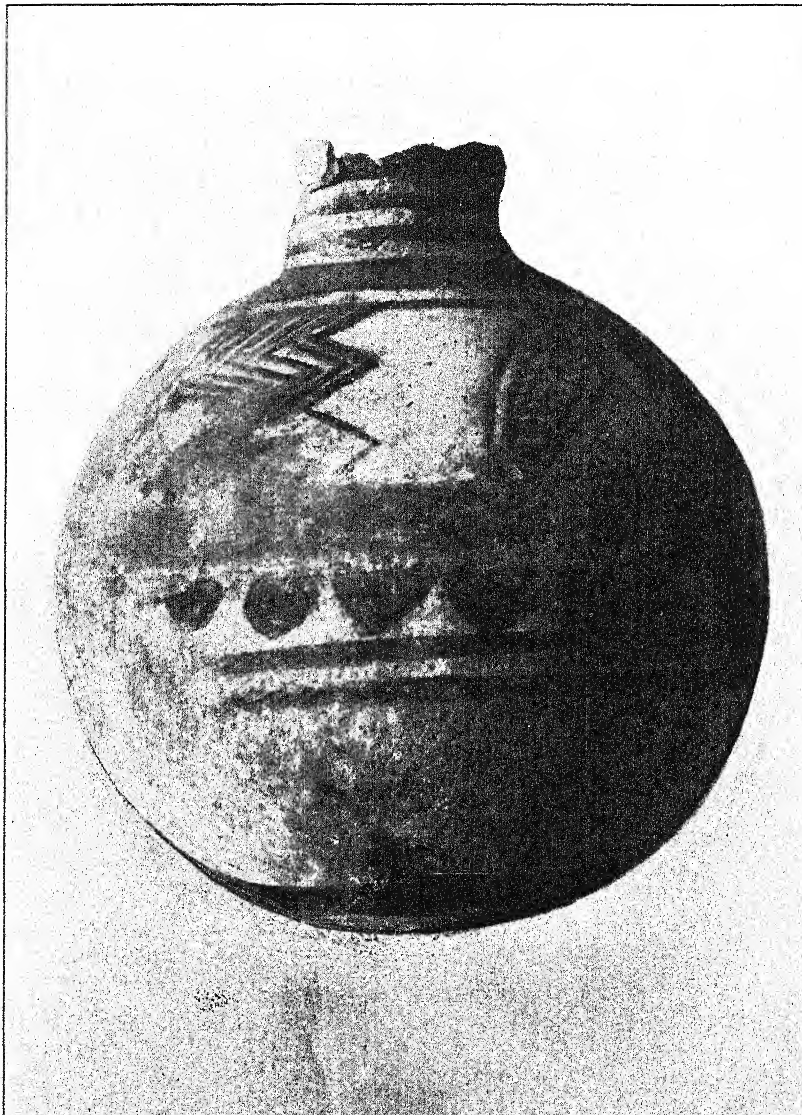
GREAT COURT OF THE TEMPLE

Work on the Nannar Temple has been of a very different sort and deals with much later dates. On Mr. Mallowan's arrival on December 10, I engaged a fresh gang of 50 men and put them in his charge for the clearing of the chambers along the front of the temple, the courtyard of which we had cleared last season.

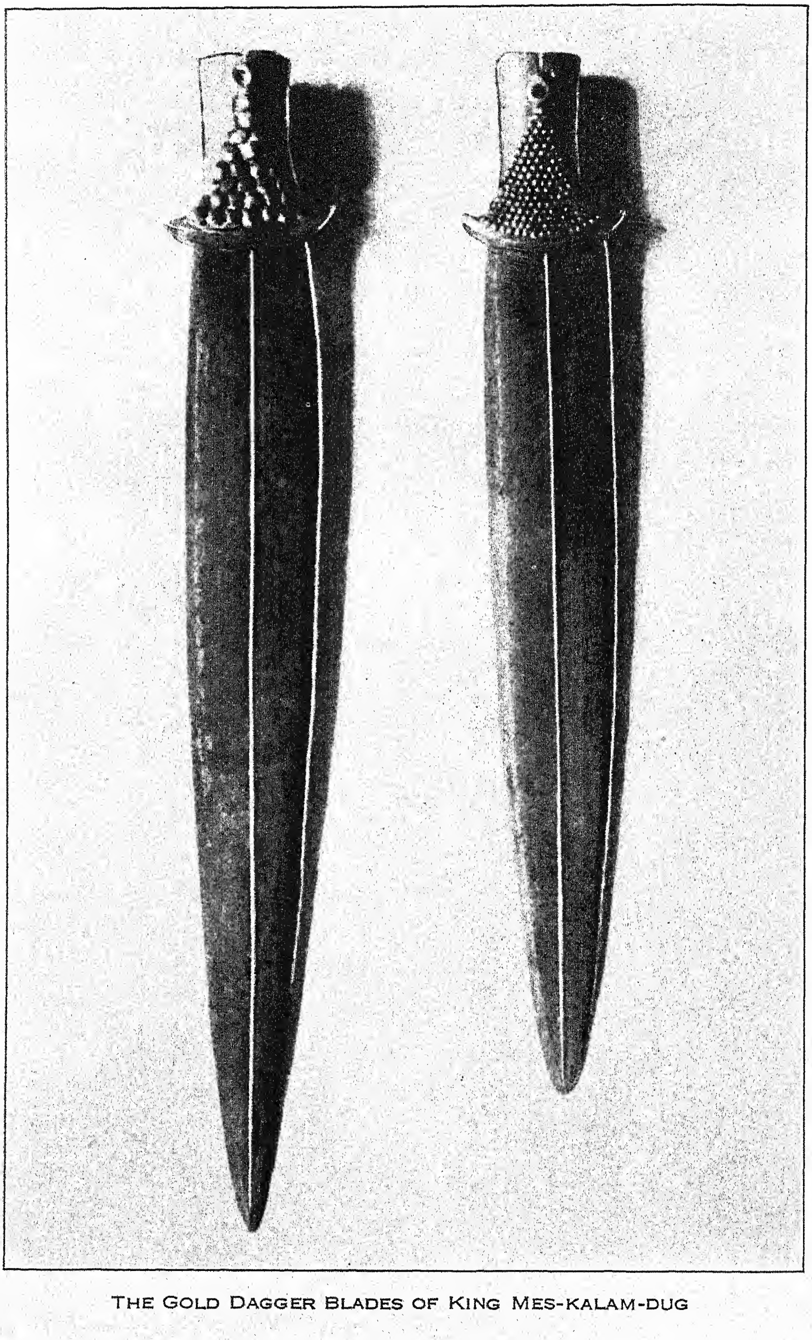
The general character of the building was already known from surface clearing; our object this year was to trace the details of its history, and in this we have been eminently successful. Vague fragments of wall were unearthed which belong to about 3,000 B. C. and tell of a temple of the moon god lying at the foot of a smaller and an older ziggurat than that which we see to-day. Ur-Engur built the present ziggurat and laid the foundations of the great temple to the patron deity of his city; the sanctuary lay against the northwest side of the tower, the huge outer court formed a lower platform whose containing walls covered a much wider area than the old temple. Ur-Engur did not live to finish his work, and his son Dungi built the superstructure, the pylon gateway at the entrance of the temple and the range of chambers which surrounded the courtyard on whose pavement stood the altars or bases of his father and himself and, in time, of his son Bur-Sin. After the downfall of the splendid third dynasty of Ur a king of Isin filled up half the courtyard with a massive brick structure whose meaning is not yet clear to us, and a later ruler, Sin-Idinnam of Larsa (c. 2000 B. C.) blocked the

court still further with a base whose foundations go down to prehistoric levels. But these were minor changes; it was left for the Elamite king Warad-Sin to remodel the whole temple. He enlarged the building in three directions, putting up a new retaining wall for the terrace outside the old wall the stump of which was buried under the floor of his chambers, and the whole of the exterior and the wall of the courtyard facing the entrance were enriched with half-columns and recesses of burnt and crude brick. Five hundred years later what remained above the ground of Warad-Sin's work was dismantled and on its foundations Kuri-Galzu II of Babylon (c. 1400 B. C.) set up a plainer replica of the Elamite temple; much of the existing building is due to him. Apart from minor details, such as the repaving of the court by another Babylonian king about 1180 B. C. and the raising of its level by the Assyrian governor Sin-Balatsu-Ikbi in the seventh century, the temple retained its character until the time of Nebuchadnezzar (600 B. C.). He built two new sanctuaries on the ziggurat terrace, raised the pavement of the great court virtually to the same level and added to the pylon gateway by bringing it forward into the court, with side doors to the northeast range of chambers which he masked by a curtain wall. The rooms cleared so far have not produced any tablets; two inscribed door sockets have been found but the best object is one which has no real connection with the present building, a limestone mace head with figures of man-headed bulls in relief and an inscription, unfortunately much defaced, which may refer to a king of Mari and certainly belongs to about that period.

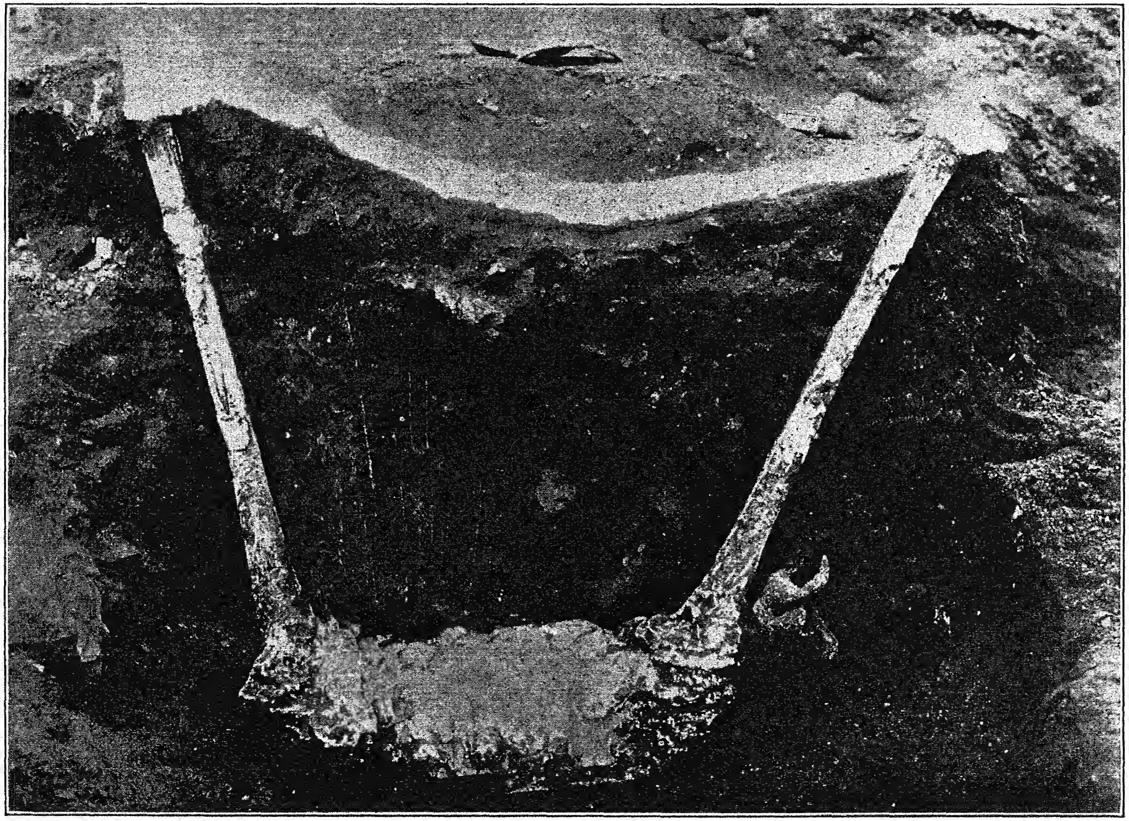
Thus we can now trace through its long life of 2,500 years the vicissitudes of the greatest temple of Ur, and with its excavation have practically finished our work in this part of the city.



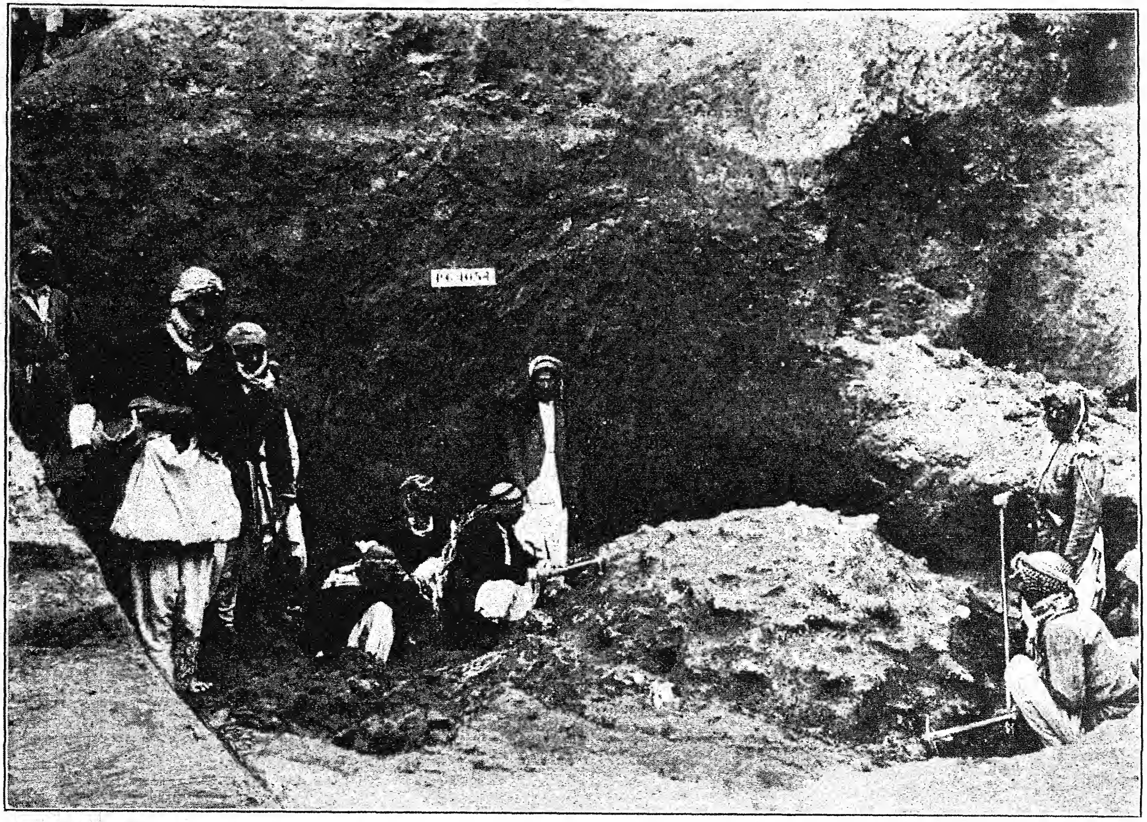
PAINTED POT OF THE JEMDET NAST TYPE



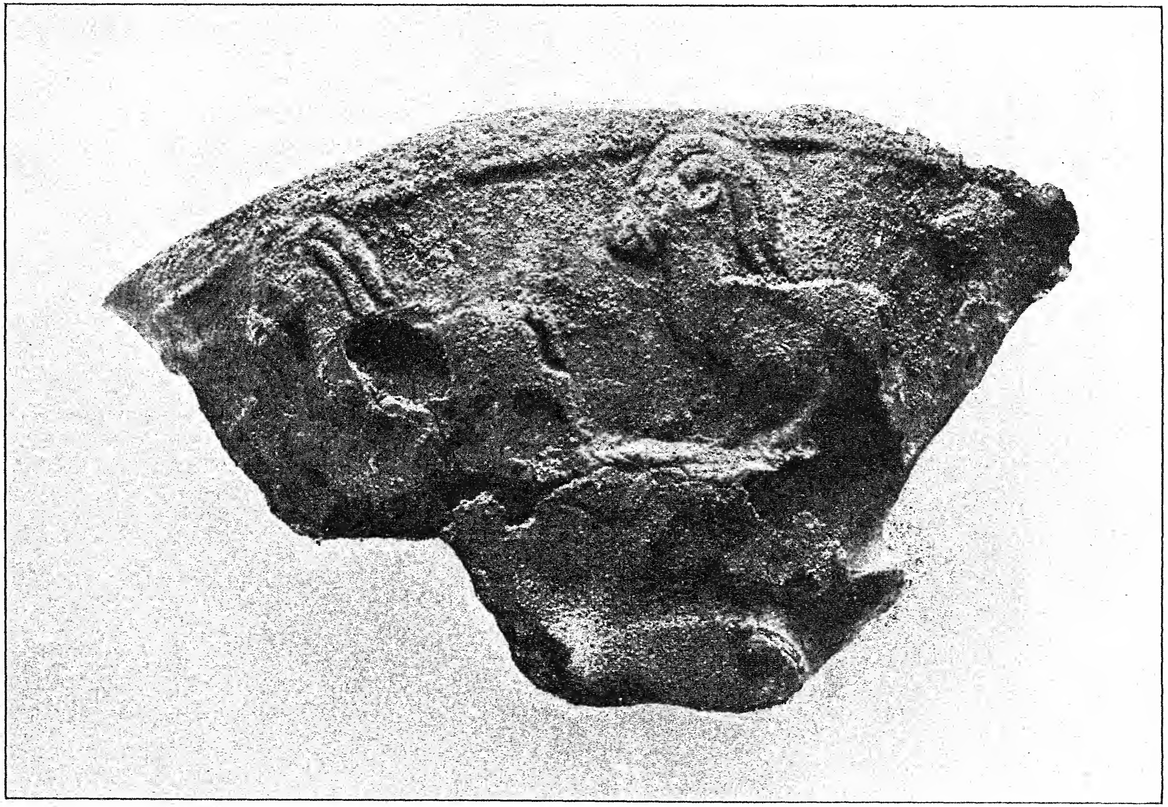
THE GOLD DAGGER BLADES OF KING MES-KALAM-DUG



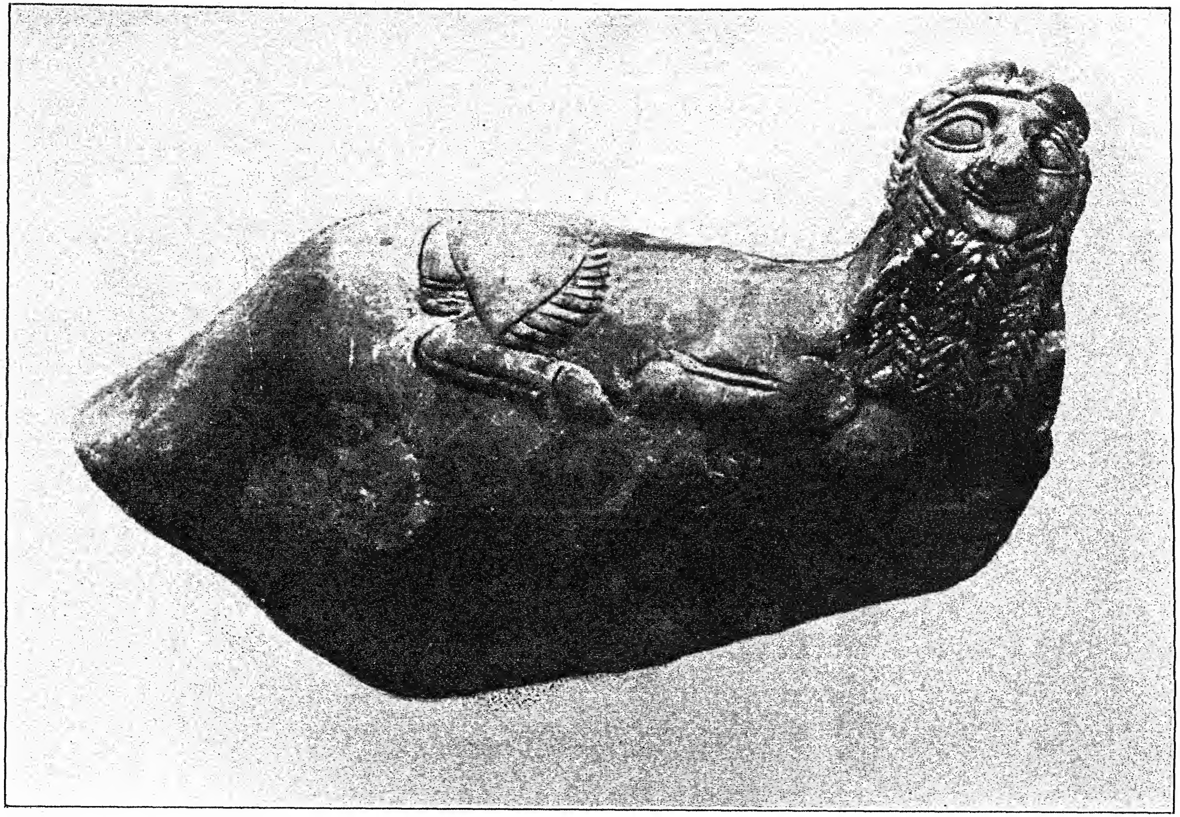
PLASTER CAST OF THE HARP STILL IN THE SOIL. THE STRINGS CAN BE SEEN ON THE LEFT



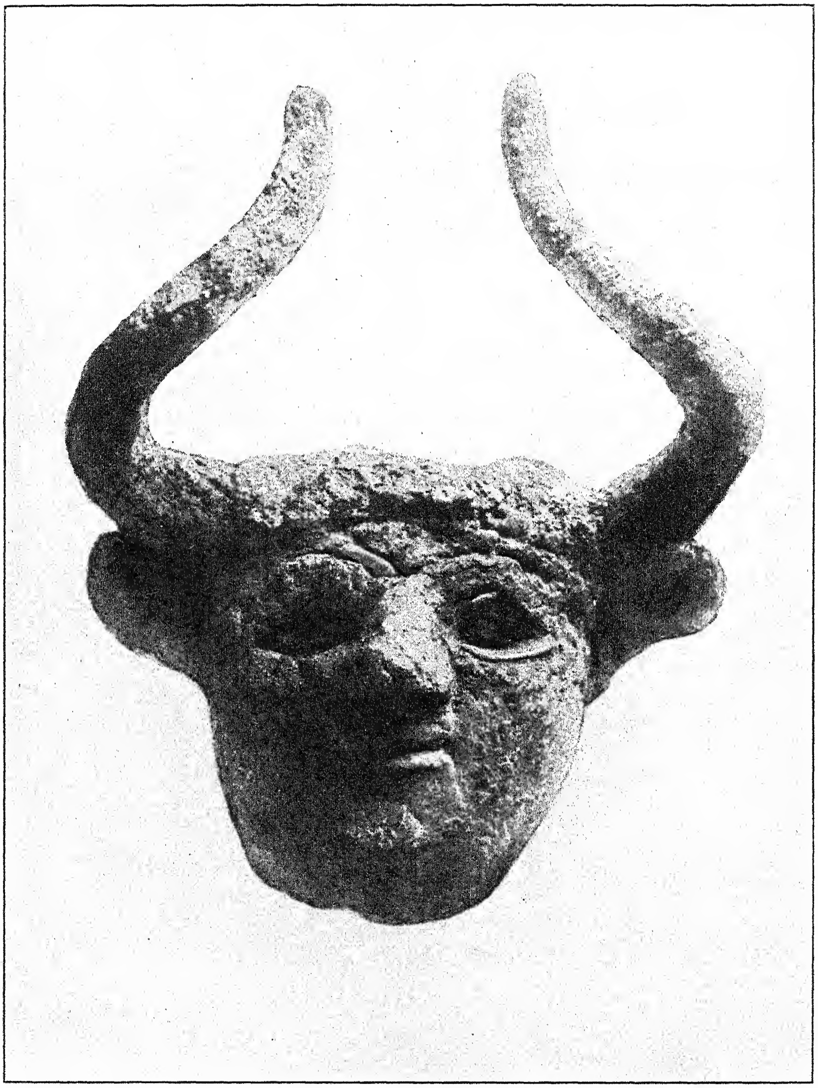
CLEARING THE CROWN OF THE STONE DOME OF P. G. 1054. BEAM HOLES FOR CENTERING ARE VISIBLE



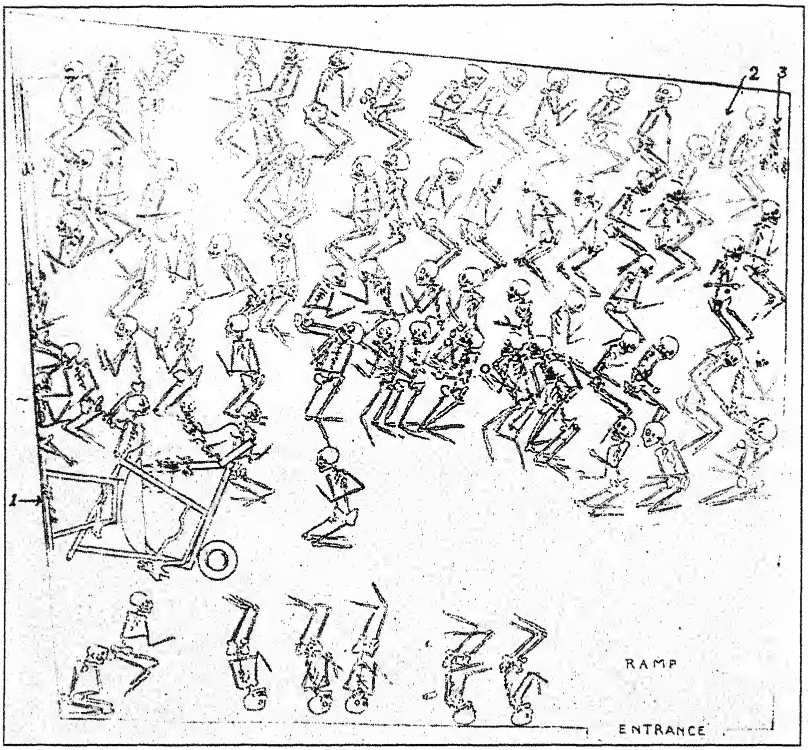
SILVER BOWL WITH REPOUSSÉ DESIGN



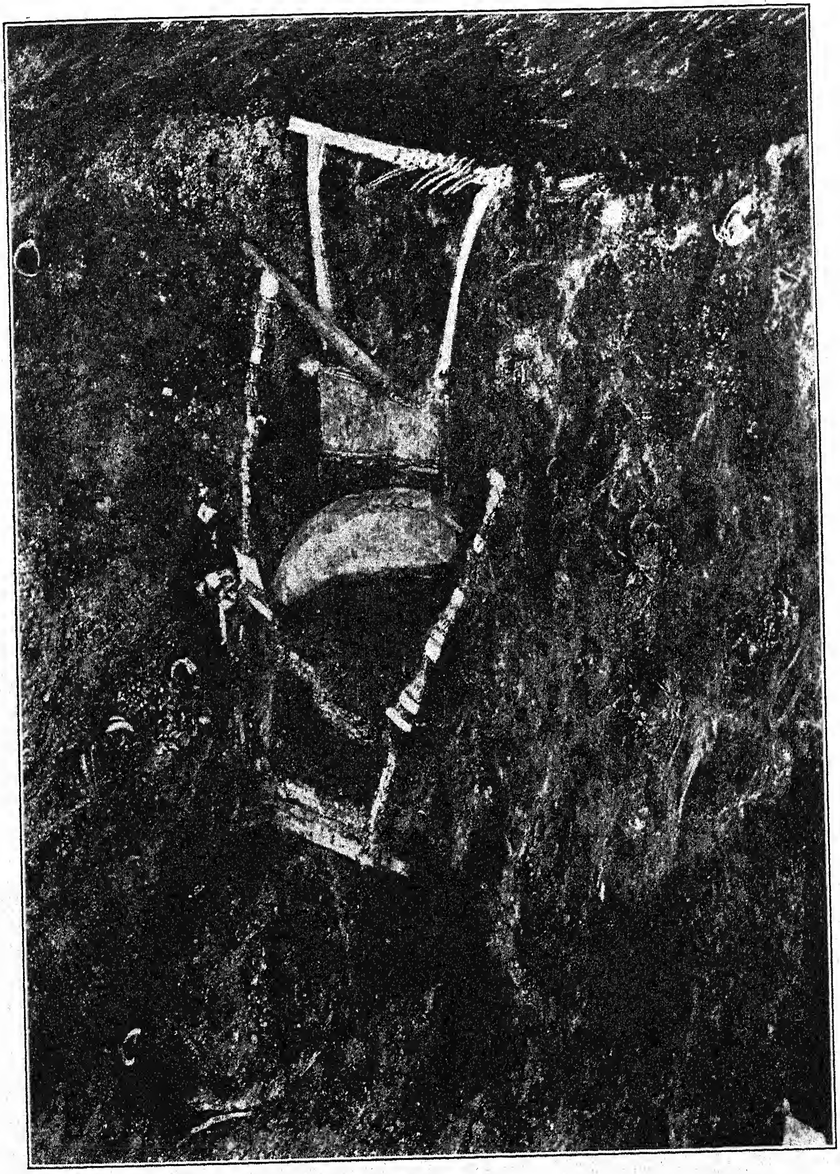
ALABASTER LAMP. U. 11799



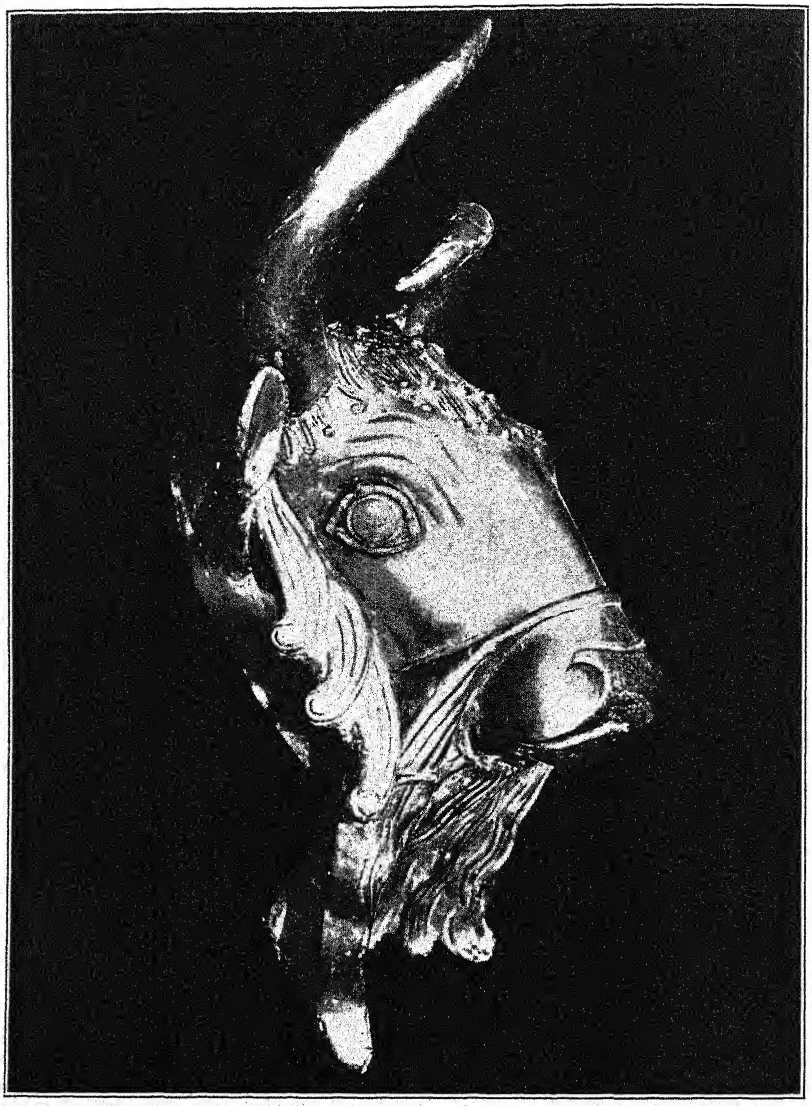
COPPER HEAD OF A HORNED GOD WITH EYES AND EYEBROWS INLAID. U. 11798



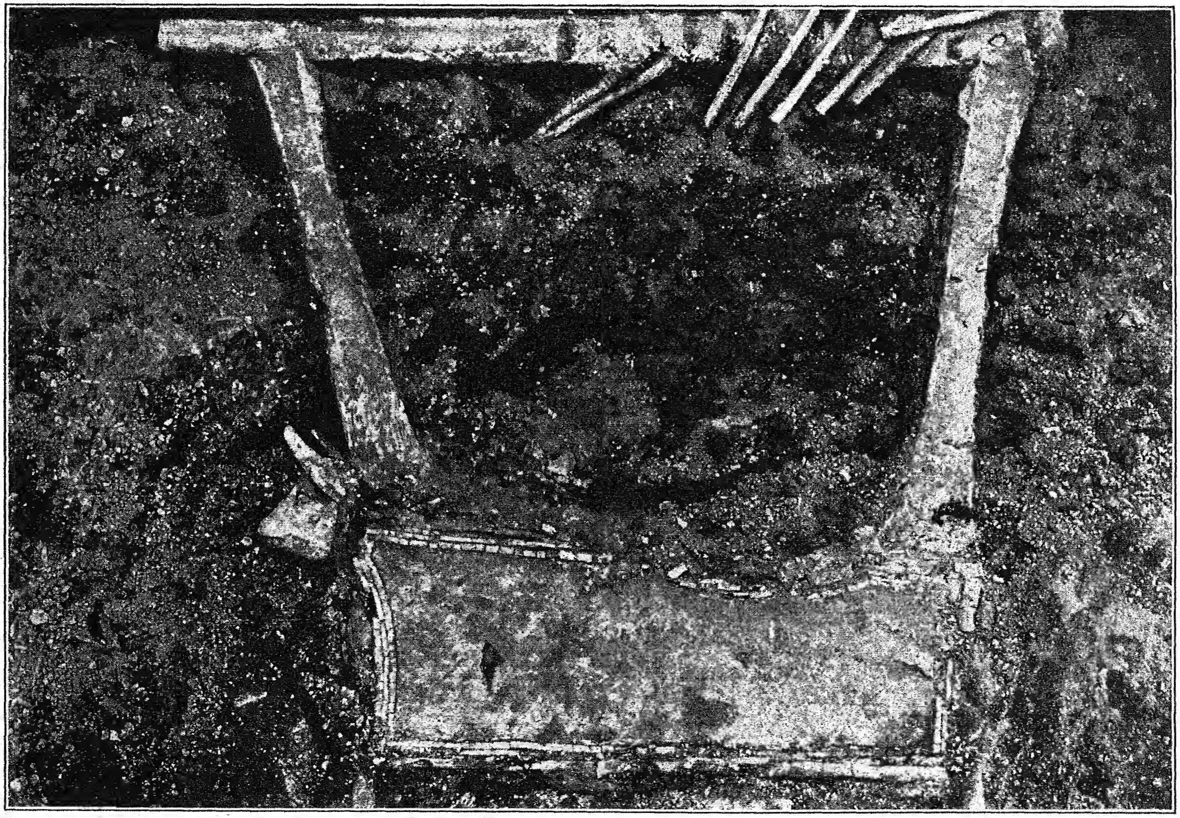
PLAN OF THE DEATH PIT SHOWING BODIES AND OBJECTS IN POSITION, THE HARPS ON THE LEFT, THE STATUES OF RAMS IN THE UPPER RIGHT



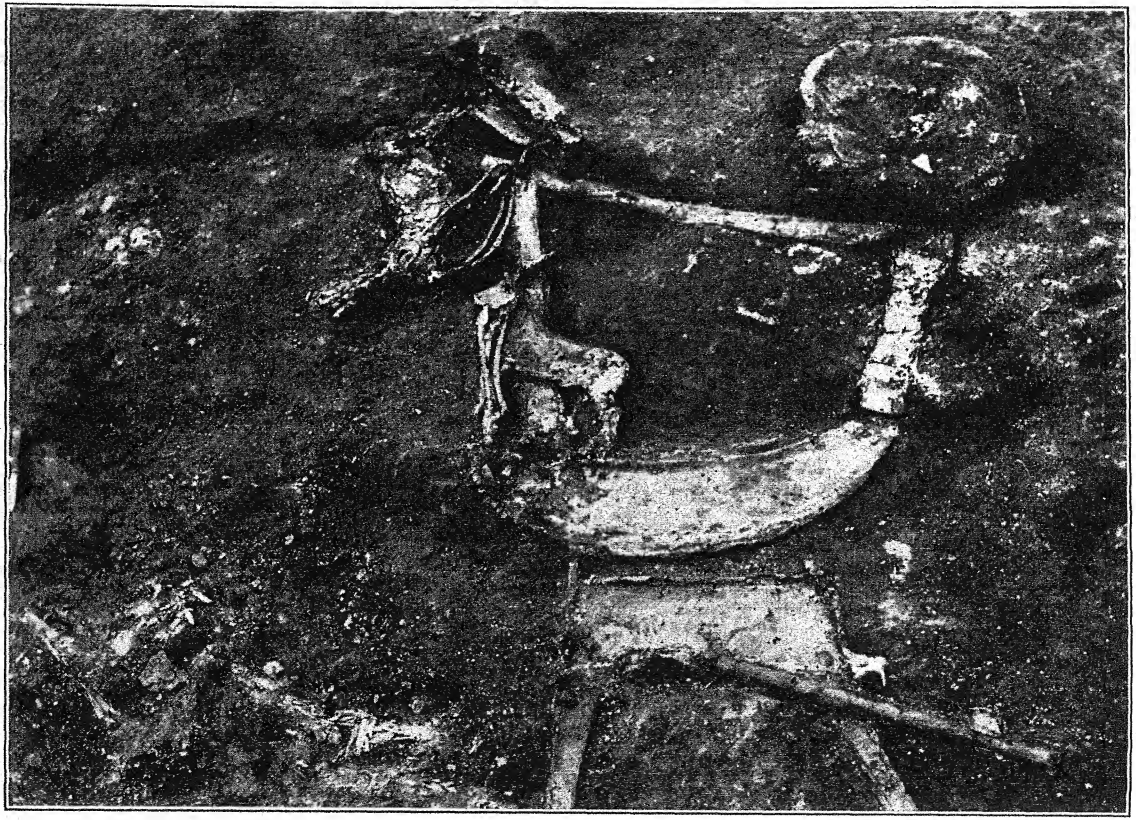
GROUP OF HARPS IN POSITION



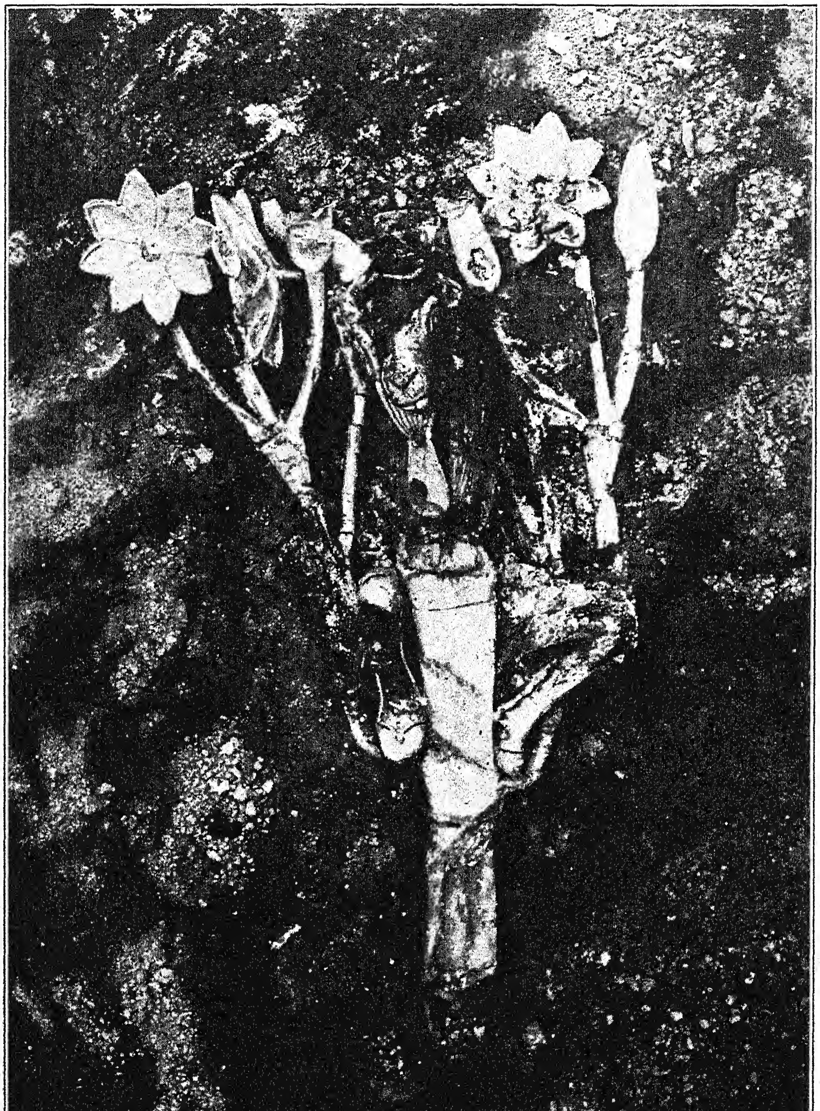
THE GOLD BULL'S HEAD FROM THE FIRST HARP



THE SILVER HARP, NO. 2



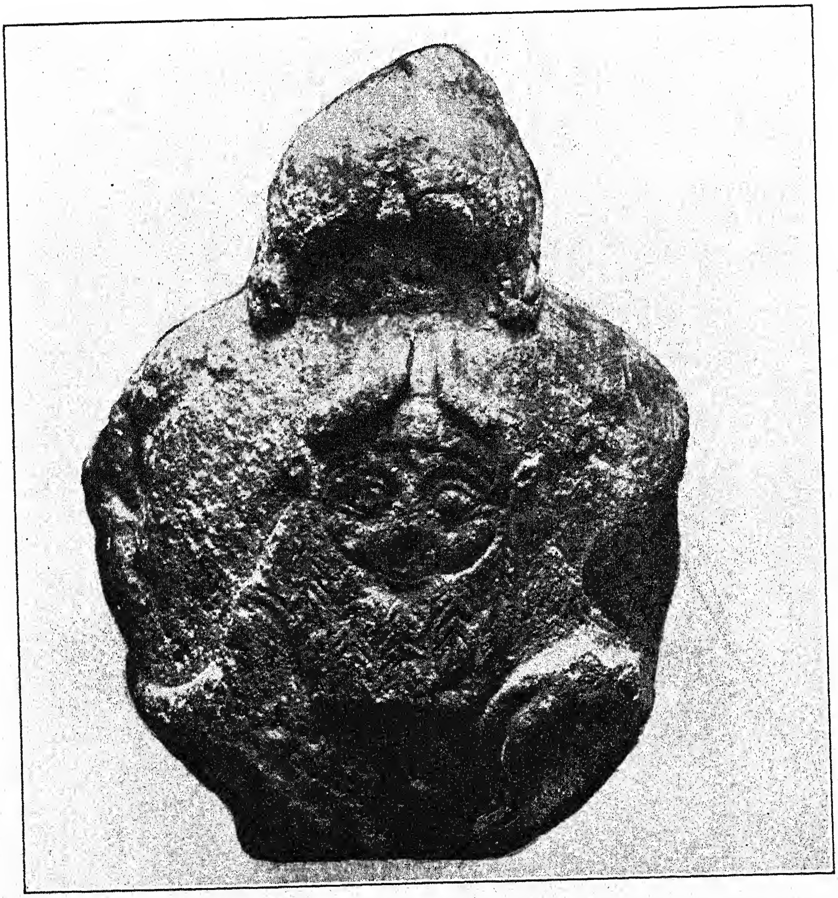
THE SILVER HARP WITH A STATUE OF A STAG. THE REMAINS OF A COPPER STAG ARE SEEN ABOVE



THE RAM CAUGHT IN A THICKET. FRONT VIEW. COMPOSITE FIGURE IN THE ROUND OF GOLD, SILVER, AND SHELL

THE SECOND RAM, SEEN IN PROFILE IN THE GROUND

1. SHELL INLAY. SUMERIAN CHIEF WITH AX, HELMET, AND FALSE BEARD



2. LIMESTONE MACE HEAD. U. 11678

SHELL INLAY BELOW A HARP

LARGE STONE TOMB. FIRST ROOM BEFORE REMOVAL OF THE VAULT

THE POPULATION OF ANCIENT AMERICA[1]

By H. J. SPINDEN

Peabody Museum, Harvard University

[With 1 plate]

What is the Indian population in America to-day, and is it increasing or decreasing? Was it as large in 1492 as it is now or as it had been in some earlier period of New World history? These questions I hope to answer not so much with statistics as with suggestive considerations. Indeed, exact figures are not available even for the proportion of Indian blood in the present population of America and it is obvious that the speculative factor must become larger and larger as we pass back through the centuries.

PRESENT INDIAN POPULATION

The present Indian population in the New World is much larger than most persons might imagine from their knowledge of conditions north of Mexico. For Greenland, Canada, Alaska, and the United States the number is less than 400,000, with considerable admixture of foreign blood for which a proportional discount must be made. For the United States the most reliable count of Indians was the census of 1910, which found 265,683 individuals. Of this number 150,053 were full bloods, and the others mixed bloods with a distinct leaning toward white. The census of 1920 showed a reduction of 21,246 from the figures for the preceding decade. The counts made by the Bureau of Indian Affairs differ widely from those of the general census, since in some cases persons with one sixty-fourth part Indian blood are called Indians. Also the tribal rolls used by the bureau, in spite of various purgings, carry a large number of negro "freedmen" who may or may not have old American blood. For 1920 the aboriginal population according to the bureau was 336,379, or 91,942 in excess of the census of that year. Fluctuations, explained mainly by reorganization of the rolls, are apparent in the following totals for different years:

1870	313, 712	1887	243, 299
1877	276, 540	1900	270, 540
1885	344, 064	1926	349, 964

[1] Reprinted by permission from The Geographical Review, vol. 18, No. 4, 1928.

Probably the Indian strain in the United States, counting proportional values only, is equivalent to about 200,000 individuals of pure blood, with claims of recent increase unjustified. The Navajo and one or two other tribes have more than held their own, but except for these a general decrease is indicated.

What a difference when we turn to Mexico! There the census of 1900 found a total of 13,605,819 inhabitants, classified as 19 per cent whites, 38 per cent Indian, and 43 per cent mixed bloods. The census of 1910 gave the total as 15,160,369, but by 1920 this had receded to 14,234,852, perhaps as a result of civil war and emigration. It is difficult even to estimate the proportion of Indian blood in the total population of Mexico, since classification is formed on the language basis. The statistical Indian is one who speaks an Indian language, generally to the exclusion of Spanish.

We have one excellent study of a special region, the Valley of Teotihuacán, which was made by the Department of Anthropology of the Mexican Federal Government.[2] The total population of the Valley of Teotihuacán is 8,330, of which 6,825 are of local origin, 1,477 come from other districts of Mexico, 10 are foreigners, and 18 unclassified. In the matter of race 5,657 are Indians, 2,137 are mixed bloods and 536 are whites. But of the total, 7,860 speak Spanish, 448 both Indian and Spanish, while 7 speak only an aboriginal tongue. The proportion of Indian blood in this instance is almost 80 per cent; but whether or not this proportion would hold true of all Mexico is another question.

Indian community life and language are preserved in many regions of Mexico to a much greater extent than in the Valley of Teotihuacán. The statistics on native tongues are not reliable, but according to the census of 1900 they are spoken by 3,971,434 individuals. Playing safely within the estimates of several observers but remembering the high proportion of Indians who have lost their native speech, we conclude that the Indian blood in Mexico is equivalent to a pure population of at least 10,000,000 souls.[3]

Other Central American and South American countries where the Indian forms a very high percentage of the total population are Guatemala, Salvador, Honduras, Colombia, Ecuador, Peru, and Bolivia. Elsewhere the proportion is always considerable even in the cases of Argentina and Chile, which fail to make adequate return in their censuses of such Indian blood as does survive among acculturated aborigines.

---

[2] Manuel Gamio: La poplacion del valle de Teotihuacán * * * 2 vols. in 3, Department of Anthropology, Mexico, 1922; Reference in Vol. I, Pl. II and pp. xxii–xxiv. In the English summary, "Introduction, synthesis and conclusions of the work, The Population of the Valley of Teotihuacán" reference is Pl. III and pp. xxi–xxiii.

[3] If the "mixed race" classification of the Mexican census be taken as half Indian we have nearly 70 per cent for the total of Indian blood, but it is obviously more than half Indian.

Always making allowance for mixed bloods at proportionate value, we summarize thus:

North America north of Mexico	350, 000
Mexico	10, 000, 000
Central America	2, 500, 000
Colombia and Venezuela	3, 000, 000
Ecuador, Peru, and Bolivia	6, 000, 000
Brazil, Paraguay, Uruguay, and Guianas	4, 000, 000
Argentina and Chile	200, 000
West Indies	
	26, 050, 000

This gives a conservative minimum of 26,000,000 for the red race at the present time.[4] We now look into the past and consider the evidences of population, first at the coming of Europeans, and then on more ancient levels of the native civilizations.

THE DEPOPULATION OF THE WEST INDIES

In the West Indies hardly a drop of the old American blood can now be found. Indeed, the Spaniards had scarcely set foot on the teeming islands before the native population melted away. Santo Domingo was colonized in 1493, Porto Rico and Jamaica in 1509, and Cuba in 1511. Las Casas in his famous "Brief Relation" says in regard to Porto Rico and Jamaica[5]: "Whereas there were more than 3,000,000 souls, whom we saw in Hispaniola, there are to-day, not 200 of the native population left." He was writing no later than 1542. Elsewhere Las Casas places the population of Porto Rico at 800,000 and that of Santo Domingo at 3,000,000. These are doubtless extravagant estimates. However, on the basis of personal surveys of many archeological sites in Porto Rico, I postulate a population of at least 100,000. Santo Domingo, a much larger island, is archeologically almost unknown; but, since characteristic remains of the ancient Taino culture[6] extend from Porto Rico across Santo Domingo to the eastern end of Cuba, the total population of the Taino nation may easily have been a million. It is clear that Cuba, except for the region

[4] Karl Sapper in "Die Zahl und die Volksdichte der indianischen Bevölkerung in Amerika von der Conquista und in der Gegenwart" (Proc. 21st Internatl. Congr. Americanists held at The Hague, Aug. 12–16, 1924, Part I, pp. 95–104) estimates the present (1910) Indian population of America at between 15 and 16 millions and that at the end of the fifteenth century at between 40 and 50 millions. The paper is summary in form and undocumented. Sir Harry Johnston in "The Negro in the New World" (1910) estimates at "20,855,000 hybrids between the white and the Amerindian" and "16,000,000 of pure-blood Amerindian and Eskimo" in the New World (p. 484.)

[5] F. A. MacNutt: Bartholomew de Las Casas, His Life, His Apostolate, and His Writings, p. 316, New York, 1909.

[6] J. W. Fewkes: The Aborigines of Porto Rico and Neighboring Islands, 25th Ann. Rep. Bur. Amer. Ethnol. 1903–04, pp. 3–296, Washington, 1907. M. R. Harrington: Cuba before Columbus, Part I, Vol. I (Indian Notes and Monographs, Misc. Ser., No 17), Museum of the American Indian, Heye Foundation, New York, 1921.

about Cape Maisi, was scantily peopled. Jamaica and the Lesser Antilles offer considerable evidence of ancient human habitation but not of a kind permitting even a rough estimate of numbers.

IMPORTED DISEASES AS A FACTOR IN DEPOPULATION

Even if we take Las Casas' estimates at one-tenth their values, the eradication of the natives in a generation is difficult enough to explain. This could not have been accomplished by wholesale slaughter with the sword, considering the available forest cover and mountain retreats, but it might have been accomplished by epidemics of new diseases which searched out native villages far beyond the Spanish lines. Early mortality among the Indians is mentioned by Oviedo and other chroniclers. It seems that the so-called colonization of Santo Domingo was first of all a gold rush, with the natives suddenly exposed to a host of new diseases and to a condition of slavery under a heterogeneous and undisciplined mob. While starvation and these new diseases were probably the most active agents of sudden decrease in population, nevertheless the situation was commanded by a policy of frightfulness which caused a social collapse so complete that even the victors nearly perished of famine. The Spaniards gave no thought to planting crops, intent only on a fevered turning over of the ground in search of the yellow metal.

Devastating diseases pretty clearly of New World origin are syphilis and yellow fever.[7] To the first of these the agricultural Indians, especially those of Peru, Mexico, and the West Indies, had developed considerable immunity. Yellow fever was endemic in the Atlantic lowlands of Mexico and Central America, occasionally invading the highlands.

Europeans unloaded upon American Indians a tremendous burden of new infections for which the latter had not the slightest immunity. Perhaps smallpox comes first as an introduced plague and measles second, this latter malady being very deadly for the red man. But in the tropics the debilitation and mortality resulting from the introduction of malaria in three types and hookworm in two are heavy factors. There have been great epidemics of several other diseases, including Asiatic cholera. In recent years trachoma has been a burden among many tribes. High mortality among the aborigines has generally followed the opening up of new territories by the white men.

The small number of serious forms of disease in pre-Columbian America is explained first by the independence of New World civiliza-

[7] Anthropologists have long insisted that syphilis was of New World origin, but the medical world after disputing the evidence is now accepting it. The case for the American origin of yellow fever is equally strong. This disease was implanted in Africa by slave traders, and some medical opinion now leans inconsistently to Africa as its cradle land (H. J. Spinden: Yellow Fever—First and Last, World's Work, Vol. 43, pp. 169–181, 1921).

tions. We must picture the tenuous connection between the hemispheres, consisting of nomads passing via Siberia and Alaska, as insufficient for the transmission of such pathological organisms as might already have attacked the thicker settlements of the Old World. Furthermore, few gregarious animals were brought under domestication in America to prove new sources of malevolent infection.

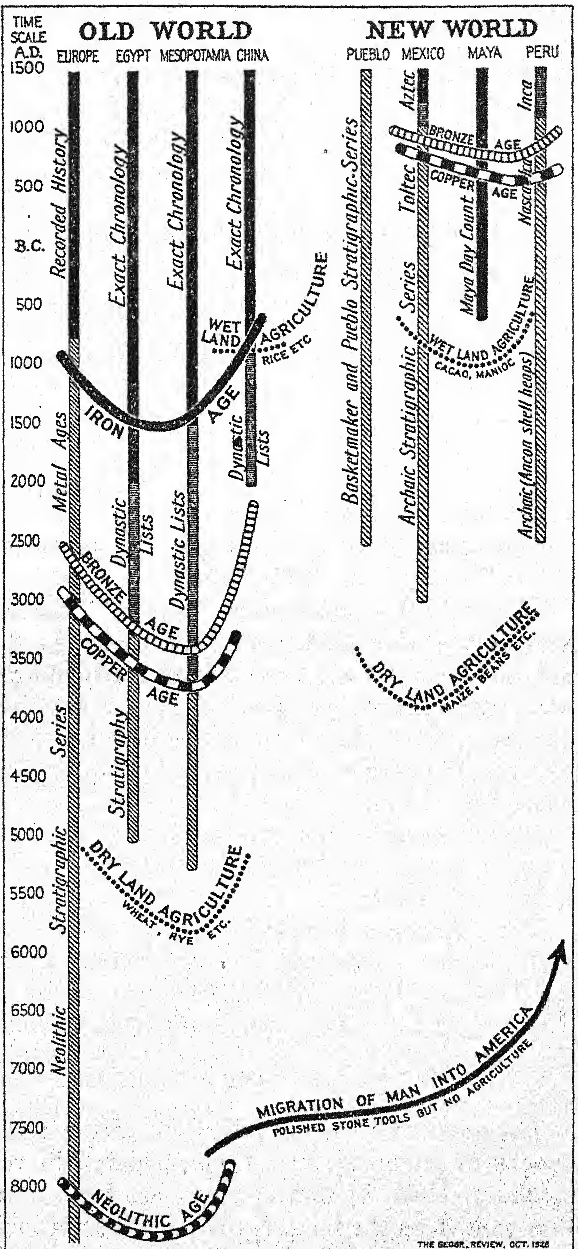


FIGURE 1.—Chronological and economic diagram of the parallelism between Old and New World civilization which presents in summary form some of the facts bearing on the question of the population of ancient America. Note that the stratigraphic series of Europe is only carried back to the horizon of polished Celts. Before this come the Mesolithic and Paleolithic series which are not represented in the New World.

THE TEN PLAGUES OF NEW SPAIN

In Mexico the Spaniards struck sharply and deeply, while illusion of their divinity and magic power still obsessed the aboriginal populace. Nevertheless, they might easily have failed if reinforcements of invisible parasites had not come up in time. Between the retreat of Noche Triste and the final taking of Tenochtitlan smallpox fought most valiantly on

the side of the invaders and finally turned the battle definitely in favor of Christianity.

Friar Toribio de Benevente, commonly called Motolinia, arrived at Vera Cruz in May, 1524, and his "History of the Indians of New Spain" was finished in 1541.[8] He draws a tremendous picture of events and conditions which reduced the native population by comparing Ten Plagues of New Spain with the biblical Ten Plagues of Egypt. I can not give the gist of depopulation better than by using the words of this priest:

> God smote and chastized this land and those who found themselves in it, natives as well as strangers, with 10 burdensome plagues.
>
> The first was smallpox, and it commenced in this manner. Hernando Cortes was captain and governor when Captain Panfilo de Narvaez disembarked here, and in one of his ships came a negro suffering from smallpox, a disease never before seen in this land. Then this New Spain was full of people to the extreme and as the smallpox began to catch among the Indians there was so great a malady and pestilence among them everywhere that in most of the provinces over half of the people died and in others scarcely less.
>
> Eleven years later came a Spaniard with measles which passed from him to the Indians * * * and many died.

Motolinia then gives other "plagues," the second being the heavy mortality at the taking of Tenochtitlan; the third, the famine which resulted from the widespread warfare; the fourth, the abuses of overseers in the towns given in vassalage; the fifth, the heavy tributes; the sixth, the tremendous abuses in connection with the mines; the seventh, the construction of Mexico City by forced labor; the eighth, the traffic in branded slaves; the ninth, the abuses of transportation with Indians as human beasts of burden; and the tenth, the factional warfare among the Spaniards themselves with Indians bearing the brunt of fighting.

The charges of Motolinia were those of a contemporary witness, and they are borne out by legal papers against Cortes, Alvarado, etc., and by such native documents as the Codex Kingsborough. The juggernaut drama was reënacted in Colombia and Peru.

ON THE RECOVERY OF INDIAN POPULATIONS

The great and sudden falling off in the Indian population during epochs of conquest must be considered in relation to increase or recovery, which in some regions has been notable. In the United States perhaps the most remarkable case of increase over early numbers is that of the Navajo. This tribe secured sheep, became pastoral

---

[8] (Fray) Toribio de Benavente o Motolinía: Historia de los Indios de la Nueva España, pp. 13–14, Barcelona, 1914. For another important reference on depopulation see Juan López de Velasco: Geografía y descripción universal de las Indias: Recopilada por el cosmógrafo-cronista Juan López de Velasco desde el año de 1571 al de 1574, publicada por el primera vez en el Boletín de la Sociedad Geográfica de Madrid, con adiciones é illustraciones, por Don Justo Zaragoza, p. 26, Madrid, 1894.

without much modification of their original wandering life, and in two centuries quadrupled without admixture of foreign blood.

In Mexico also there has been a rapid increase from low records of the Spanish régime, as may be seen by comparing the figures collected by Humboldt[9] with those of today. For 1803 the German traveler makes the population of Mexico 5,837,100; classified as 18 per cent white, 60 per cent Indian, and 22 per cent mixed. The area covered is not exactly the same as that of today; but the state of Chiapas, then counted with Guatemala, serves to counterbalance parts of the Southwest which now belong to the United States. The increase is about 150 per cent in 125 years, and the Indian part of the population seems to hold its own proportionally or perhaps to gain if we eliminate immigrants. The Maya territory in the peninsula of Yucatan is an exception to the general advance. Humboldt gives the population of the political district of Mérida (which seems to have included Campeche) as 465,800 and that of Valladolid as 476,400, making a total of 942,020 for the Mexican proportion of the peninsula.[10] This may have been an overestimate, but a very great falling off resulted from the terrible War of the Castes precipitated by the sending of several shiploads of Maya Indians to Cuba as slaves. This war broke out in 1848 and resulted in abandonment by white landowners of much of eastern and central Yucatan. Parts afterwards pacified were never able to retrieve the earlier prosperity.

Of Guatemala in 1778 Juarros[11] says:

> The larger and principal part of these lands was captured by Capt. D. Pedro de Alvarado in the year 1524 and following. In that time these countries were much more populated than at present since according to the count made by order of His Majesty in the year 1778 this kingdom has no more than 797,214 inhabitants; while in the time of its conquest its inhabitants were innumerable, so much so that they comprised more than 30 nations.

But the Guatemala of Juarros covered all the territory between Mexico and Panama and even included the present Mexican State of Chiapas. Now this area supports about 6,000,000 inhabitants. While part of this total is covered by immigration, a very great increase is generally to be noted for Indians living agricultural lives in open country. I have elsewhere given the present Indian population of Central America in round numbers as 2,500,000. A missionary living on the populous Guatemalan highlands estimates that there are at present 750,000 Indians speaking native languages and maintaining parts, at least, of the ancient culture. These are ranked as

[9] Essai politique sur le royaume de la Nouvelle-Espagne (Voyage de Humboldt et Bonpland, Part III), 2 vols. and atlas, Paris, 1811; reference in Vol. i, pp. 152 et seq.

[10] *Ibid*, p. 155.

[11] Domingo Juarros: Compendio de la historia de la ciudad de Guatemala (2 vols., Guatemala 1808–18), Vol. i, p. 8; English transl. by J. Baily: A Statistical and Commercial History of the Kingdom of Guatamala in Spanish America, p. 10, London, 1823.

peons; and some 300,000 of them are compelled to migrate to the unhealthy coffee regions of the coast for part of the year—a necessity which has resulted in heavy mortality. Others serve as burden-bearers to escape the classification of forced labor. It is possible to demonstrate from the detailed statistics in the surveys of Velasco, Juarros, etc., that the Central American Indians have remarkable vitality in recovering population losses.

We need not follow much farther the statistical record of recovery of Indian populations from the lows reached after the incoming of Europeans. The Indian survival in the West Indies is negligible,[12] but it happens that about 5,000 so-called black Caribs, former residents of St. Vincent, were dumped in 1793 on the then deserted island of Ruatan by the English for trafficking with the French. They were strongly intermixed with negroes, and to-day their descendants might be taken for negroes were it not that they talk and live like Caribs. This people now number about 30,000 souls; and their villages stretch from Stann Creek, British Honduras, to Carib Town, Nicaragua.

Evidences of recovery must be taken in conjunction with other evidences of continuing decrease. For instance, the Xicaque, Paya, Sumo, Guatuso, etc., in Central America are fast approaching extinction, and the same holds true of natives of the Putumayo in Colombia who are now concentrated in missions. Similar concentrations in California, Central America, Bolivia, Paraguay, and Chile long since led to complete extinction of many tribes. In Brazil the aborigines suffered heavily in the recent rubber trade, while in Tierra del Fuego sheepmen went so far as to put a bounty on their heads. It seems that sporadic increase still falls short of restoring the Indian population at the advent of the whites. But another matter awaits discussion, namely, crests of population in pre-Columbian times.

POPULATION PEAKS UNDER INDIAN CIVILIZATION

The highest civilization of the New World was that of the Mayas, whose great and numerous ruins of stone and mortar exist in a region of rain forests now practically uninhabited. Here we are dealing with a people who invented writing and mathematics in addition to architecture and who left dated records of their achievements on stone monuments which enable us to restore the chronological framework of history. It now appears certain that the Mayas were living in the humid lands at least as early as 613 B. C., when their day count was inaugurated.[13] This means that several arid-land plants, including maize and beans, had already been adjusted to wet conditions.

[12] Culin describes a settlement in eastern Cuba which still contains a little Indian blood (Stewart Culin: The Indians of Cuba, Bull. Univ. of Pennsylvania Free Museum of Sci., and Art, vol. 3, pp. 185–226, 1902).

[13] H. J. Spinden: The Reduction of Mayan Dates, Papers Peabody Museum of Amer. Archaeology and Ethnology, Harvard University, Vol. 6, No. 4, Cambridge, Mass., 1924.

The earliest "contemporary" date found (on the Tuxtla statuette) is 98 B. C., and the peak of the urban civilization of what is called the First Empire falls between 300 and 600 A. D.

But by 630 A. D. every one of the great cities had been abandoned. This abandonment may have begun about the middle of the sixth century of our era, judging from the latest dates at several cities. Speculation has been rife concerning its causes. Huntington[14] has developed a theory of climatic change, which does not seem to meet the known facts; and Cook has argued that the Central American savanas are exhausted agricultural lands.[15] But the barren savanas respond to geological conditions without evidence of having been farmed. Moreover, the dates show that cities located on the rich flood plain of the Usumacinta were abandoned at the same time as cities on the shallow-soiled plain of Petén. Warfare does not seem to have been highly developed, for none of the early Maya cities are fortified. Sanitation affords the best explanation, and it happens that yellow fever had its most likely place of origin in Central America.[16]

FIGURE 2.—Distribution of agriculture in the New World in pre-Columbian times. Numbers have reference to agriculture: 1, In arid regions of considerable altitude, mostly with irrigation; 2, under humid lowland conditions; 3, under temperate conditions

Yucatan and in fact the whole area of the Mayas is a welter of hewn stone and rubble constructions of the most massive character. Yet during the prolific First Empire the Mayas were entirely unacquainted with metals. We must picture them

[14] Ellsworth Huntington: The Climatic Factor as Illustrated in Arid America, Carnegie Instn. Publ. No. 192, Washington, 1914.

[15] Discussed by S. G. Morley in "The Inscriptions at Copan," Carnegie Instn. Publ. No. 219, pp. 452–457, Washington, 1920.

[16] The Books of Chilam Balam, Maya chronicles, record pre-Spanish visitations of yellow fever under the name xekik, "blood vomit."

cutting and carving stone with stone tools and carrying the material on their backs or dragging it over the ground from quarry to structure. It is an astonishing fact that there is no evidence of the mechanical use of the wheel in connection with traction anywhere in the New World on any cultural level. Human labor of the most strenuous sort was called for, and the vast accumulations have therefore an important bearing on population. Another fact that has often been overlooked is that the Mayas, lacking the help of draft animals, were also spared the expense. They

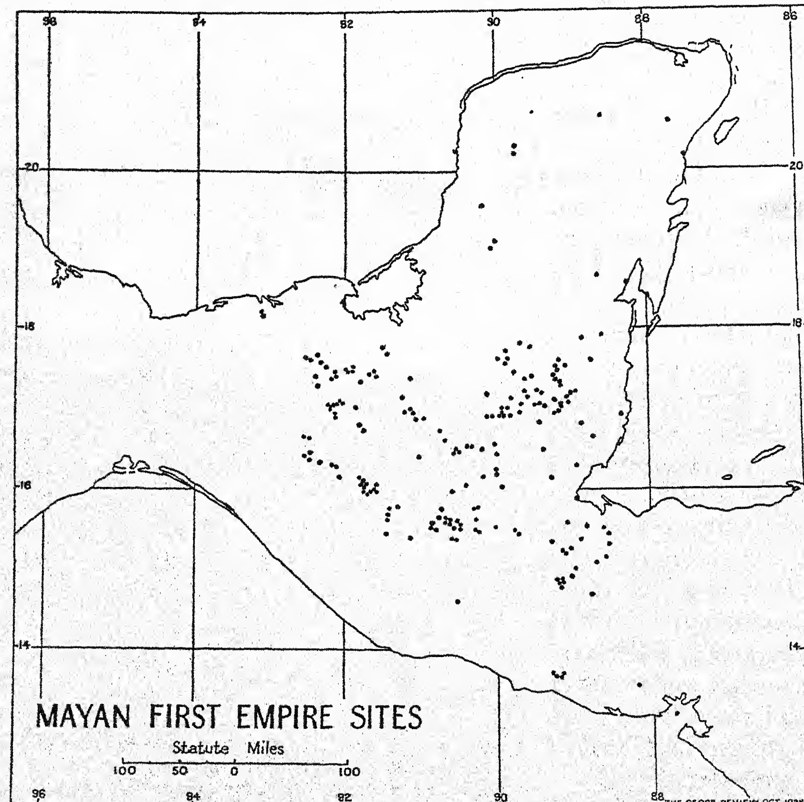


FIGURE 3.—Map showing sites of ruins of the First Mayan Empire. Scale, 1 : 16,000,000

were not forced to divide their supply of vegetable food or the land available for cultivation with hungry brutes far less economical than human beings.

I have elsewhere presented the theory that American agriculture was distributed on two distinct planes corresponding to economic development, first, of the arid lands and secondly, of wet lands, both in tropical regions, and that temperate moist-land development was

dependent upon the second plane of distribution.[17] In general this follows Harshberger's botanical evidence on the dissemination of maize.[18] In Mexico and Central America there is a safe priority of several thousand years for arid-land agriculture, and some of the plants domesticated under the régime of irrigation spread to the very limits of the New World agricultural area. The staple plants were modified to meet humid conditions probably under the stimulus of a pressure of population on food supply which induced farmers to

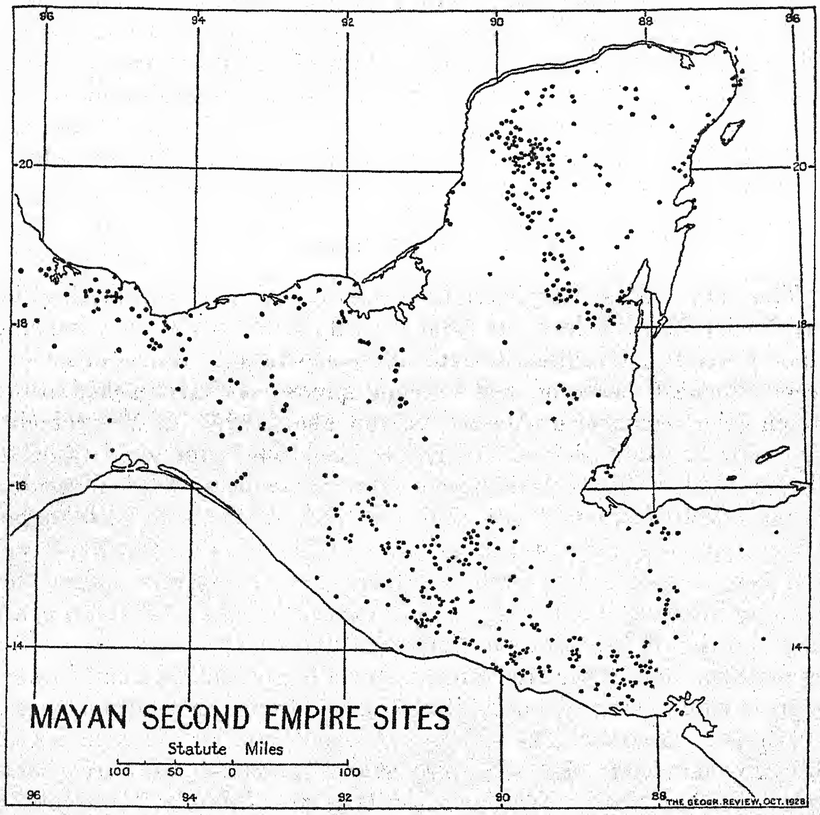


FIGURE 4.—Map showing sites of ruins of the Second Mayan Empire with the high development in northern Yucatan

invade the wet forests. On the other hand, the new plants domesticated in humid habitats had only a restricted distribution and were never developed to meet dry conditions; witness cacao, manioc, and pineapples. Perhaps the most widely distributed plants of the wet lands were sweet potatoes and peanuts, both capable of being grown in temperate regions.

[17] H. J. Spinden: The Origin and Distribution of Agriculture in America, Proc. 19th Internatl. Congr. of Americanists, Held at Washington, Dec. 27-31, 1915, pp. 269-276, Washington, 1917.

[18] J. W. Harshberger: Maize: A Botanical and Economic Study, Contr. Bot. Lab. Univ. of Pennsylvania, Vol. 1, No. 2, Philadelphia, 1893.

It appears that the dry-land culture of Mexico and Central America, traced by the vestiges of archaic art, spread first of all through arid lands into our Southwestern States and into western and northern parts of South America. Then the adaptation to the forest zone in the Mayan area took place, and the great economic success of this led to the conquest of forest areas elsewhere in Mexico and Central America, parts of South America, and the West Indies. We know from their calendar, etc., that the Mayas were established in rainy regions as early as the seventh century before Christ. If we grant an original seed population of 8,000, a peak of 8,000,000 is found after 10 doublings. This is not excessive for 1,200 years of undisturbed social evolution, and indeed it appears that the strongly urban conditions of the sixth century of our era demand an even greater number. From the archeological evidence the region of the First Empire appears to have been one of the most densely peopled parts of the world.

THE TOLTEC PEAK

The Mayan First Empire suddenly crumbled; and, considering the involved urban life in a far from friendly habitat we must imagine that this collapse resulted in tremendous mortality. Ranks of society were reformed, however, and a second minor peak was reached in the much drier region of northern Yucatan about 1200 A. D., coinciding with the activities of the Toltec kings who conquered Chichen Itza in 1191 A. D. At this time on the highlands of Mexico a strong urbanization movement was taking place. It seems to have begun among peoples near the Mayas, namely the Olmeca, the Zapoteca, the Totonacs, etc., who lived in rather wet territory of southern and eastern Mexico, and among the Chorotega on the Caribbean coast lands to the south. But the Toltecs of the Valley of Mexico got the upper hand and under Huetzin, Ihuitemalli, and Quetzalcoatl formed a great empire of trade and tribute over the sedentary nations as far south as Nicaragua. The stimulus to population on the highlands of Mexico—doubtless high and fairly stable for many centuries—came from imported food. We have seen that the Valley of Teotihuacan has a population of 8,330. Gamio says as regards its ancient population: [19]

> The extension and importance of pre-Spanish settlements in this region, vestiges of which still exist, allow us to estimate their total population to have been ten or twenty times as great as the present one, and possibly even greater * * * There is no doubt that the definite downfall of the Teotihuacan civilization was the cause of numerous migrations from the valley; yet centuries later, when the region was conquered and came under the rule of the kingdom of Tezcuco, the population was still numerous, as may be gathered by the number of tributary settlements cited in history.

[19] Gamio: op. cit.

Many persons are familiar with the tremendous pyramids of the Sun and the Moon at Teotihuacan and the great structure called the Citadel. The volume of the pyramid of the Sun has been estimated at 1,290,000 cubic yards, and its weight at about 3,000,000 tons. But the famous pyramid of Cholula, which seems to have been constructed in a comparatively short period by desciples of Quetzalcoatl in the thirteenth century, is three times as large, with a total estimated weight of nearly 10,000,000 tons. The vast terracings of Xochicalco are scarcely less impressive evidence of human labor demanding dense population. In 1927, I explored a scantily peopled section south of the city of Vera Cruz and found tremendous earthworks of the Olmeca. Then there are Monte Alban of the Zapoteca and many other vast remains of pre-Columbian Mexico and Guatemala. The evidence indicates that population on the Toltec level (1000–1200 A. D.) was much greater than when Cortes arrived in 1519 A. D. The Toltec Empire collapsed in the second decade of the thirteenth century with civil war, starvation, and disease as the designated causes.

ANCIENT INDIAN POPULATION NORTH OF MEXICO

Estimates of the ancient Indian population for the area of the United States and Canada have not been based on archeological evidence so much as on indications during some early stage of European contact. A most complete study of this area by James Mooney has recently been published as a posthumous work.[20] The total number of Indians for American north of Mexico at the advent of the whites is here estimated at 1,150,000, divided as follows: United States 846,000 Canada 220,000; Alaska 72,000; and Greenland 10,000.

Mooney's figures seem overconservative for the large part of the United States ,and yet they are lowered in detail by several writers on special fields. The densest settlement existed in California and along the Pacific coast as far north as Alaska. All the tribes of this area were on a preagricultural plane of life which was not widely nomadic, thanks to a fair food supply consisting of acorns, various wild root crops, and salmon. That these preagricultural people should have established themselves in much greater density than the central and eastern Indians of the United States who possessed agriculture seems inexplicable unless, as we surmise, the western population was near its crest when whites arrived while the central and eastern population was already depleted.

Mooney's total for California is 260,000 souls, following the figures of C. Hart Merriam based on mission statistics. Kroeber [21] reduces the population of the State for the year 1770 to 133,000. To-day it

[20] The Aboriginal Population of America North of Mexico, Smithsonian Misc. Coll., Vol. 80, No. 7, Washington, 1928.

[21] A. L. Kroeber: Handbook of the Indians of California, Bull. 78, Bur. Amer. Ethnol., pp. 880–891, Washington, 1925.

is only 15,000 indicating a decrease of 89 per cent from the smaller estimate. Even if we accept Kroeber's reduction the density of Indian population in California remains nearly four times that of the rest of the United States.

The nonagricultural Indians of America have had more difficulty meeting the competition of the whites than the agricultural Indians except those bearing the full brunt of early colonization. Their old food supply has been cut off, and violent readjustments in their mode of life have been accompanied by a rising death rate. Along the Pacific coast the salmon runs have been depleted by commercial fisheries; elsewhere wild game has been killed off, including the great herds of buffalo on the plains; while on the plateau natural gardens of camas and other edible roots have yielded to the white man's wheat-fields. Besides suffering these economic losses the nonagricultural Indians in general have been more warlike, or at least more given to resisting injustice, and have invoked their own extermination. In the case of California many tribes fell under missionary control; among these the percentage of survival is very low. Indian mortality in Oregon, Washington, and Idaho has also greatly exceeded the birth rate since the advent of the whites, the population figures for 1780 being 89,300 and for 1907 only 15,431. British Columbia and southern Alaska show nearly as bad a record.

These nonagricultural western summaries will now be contrasted with eastern agricultural ones for tribes distributed in a continuous area from the Great Lakes to the Gulf of Mexico and from the Atlantic to considerably beyond the Mississippi and well up the Missouri. The purely nomadic buffalo-hunting tribes of the Great Plains are marginal and are eliminated from the tabulation as well as all Canadian tribes except the few that practiced agriculture. The dates at the left in the following table give the eras at which Mooney calculates the population.

1600.	New England, New York, New Jersey, and Pennsylvania	55, 600
1600.	Maryland, Delaware, the Virginias, and the Carolinas	52, 200
1650.	Georgia, Alabama, Tennessee, Florida, Mississippi, most of Louisiana, and part of Arkansas [22]	114, 400
1650.	Agricultural tribes of the Central States [23]	40, 300
1696.	Agricultural tribes of the Southern Plains	12, 900
1780.	Agricultural tribes of the Northern Plains	38, 000
1600.	Agricultural tribes of southern Canada	35, 300
		348, 700

This eastern agricultural area covers about 1,375,000 square miles of territory, and the figures of Mooney give one person to four square

[22] Swanton, who edits Mooney's work, reduces these figures by about 18,000 mostly on estimates of the Creek and Chickasaw.

[23] I exclude the Ojibwa as nonagricultural until recent times. Some of the other tribes are only partly agricultural.

miles. To-day this same area, resting heavily in the matter of food on Indian plants,[24] supports a population of something like 90,000,000 individuals.

THE PROBLEM OF THE MOUNDS

Now the mute evidence of the mound culture existing in the central part of this eastern agricultural area attests rather dense population over a considerable interval of time. Mooney's data show that at the epoch of white settlement Ohio[25] and West Virginia were practically deserted and that the region of the mounds had in general a scantier population than the surrounding territory. Contrary to early theory it has now been demonstrated that the mounds were built by the ancestors of existing tribes and that some of them are of no great age, since they contain objects of European manufacture. What is the answer to this riddle? I believe that the conditions can best be explained on the theory that diseases of European origin introduced by fleeing natives from the West Indies or by Spanish explorers, such as Ponce de Leon, swept up through the mound area several generations before the establishment of the English and French colonies. But the culture of the mound builders was already decadent, and its peak must doubtless be placed several centuries before Columbus.

Shetrone[26] says of ancient Ohio:

> Perhaps no equal area in the world contains so many prehistoric earthworks as the territory comprised within the state of Ohio. The * * * recently published Archeological Atlas of Ohio locates a total of 5,396 prehistoric sites of the various classes. Of these, 3,513 are mounds proper, 587 enclosures and fortifications, 354 village sites, 39 cemeteries, 5 effigy mounds, 17 petroglyphs or pictured rocks, and 35 rock shelters or shelter caves. Besides these, 190 flint quarries and many individual burials, some graves, and other sites are located.

Some of the mounds are of large size, and their construction represents much labor. The largest mound of all is that at Cahokia opposite St. Louis, but the De Soto mound in Arkansas and the Etawah mound in Georgia are impressive constructions. The Cahokia mound is 1,080 feet long, 710 feet wide, and 100 feet high, and covers 16 acres. The volume has been calculated at 21,690,000 cubic feet. But it is only one out of many manifestations of high population in a restricted district.

In Mooney's estimate we are asked to believe that only about 150,000 Indians dwelt in the mound area at the advent of the whites.

---

[24] About four-sevenths of the agricultural production of the United States (farm values) are in economic plants domesticated by the American Indian and taken over by the white man.

[25] The Erie nation had been destroyed in 1656 by the Iroquois, and after that for half a century Ohio was uninhabited.

[26] H. C. Shetrone: The Indian in Ohio, Ohio Archaeol. and Hist. Quart., pp. 274–510, Vol. 27, 1928; reference on pp. 467–468.

This may be true if the advent is placed at 1610 A. D. instead of 1492 A. D. Also the abundant remains have been explained by imagining a small population existing for a very long time. But evidences of art and the law of population increase do not justify such dilation. It is at least seen that the concept of mounds for temple foundations can not live when generations after generations are called upon to build the substructure of the temple. Rather it seems that the eastern agricultural area must once have supported several millions and that a halcyon period a century or two before the arrival of Columbus was ended by war and the pressure of wild tribes.

THE CASE OF PECOS

In the Pueblo area abundant evidence points to an ancient régime of agriculture following an introduction of maize, beans, etc. from Mexico on the culture levels known as Basket Makers II and III. Strangely enough, the earliest finds come from a small region far removed from the Mexican border,[27] while on the following culture levels called Pueblo I and II the geographical expansion of small-town remains reaches its greatest extent towards the northwest. Pueblo III is the time level of large towns formed by consolidations of small ones, and there is a withdrawal from the northwest towards the south, without, however, any great change in the total area covered. In this brilliant period the population of the Southwest reached its maximum, and trade with Mexico was developed. The Pueblo outposts were then in the State of Chihuahua, and the Toltec outposts were close by in Durango. Pueblo art and ceremony gained new elements from their Mexican correspondents. This vitalizing contact doubtless ceased with the fall of the Toltec empire in 1220, and it is a remarkable fact that a collapse in the Southwest closely paralleled the collapse in Mexico. In part this must be explained by the raiding activity of nomadic tribes; but, whatever the causes, the area occupied by the village Indians shrank suddenly to about the present meager limits. There must have been a sharp decrease in numbers over the total area of the Southwest, and this decrease seems to have continued till comparatively recent times. At least many villages have been abandoned, and two languages, the Tano and Piro, have become extinct.

A population curve for the pueblo of Pecos has been constructed by E. A. Hooton on the basis of burials associated with pottery, which reaches a peak at about 5,000.[28] In general the results obtained are in agreement with the archeological evidence in the number of rooms

---

[27] See, for example, A. V. Kidder: An Introduction to the Study of Southwestern Archeology, Published for the Dept. of Archaeology, Phillips Academy, Andover, Mass. Papers of the Southwestern Expedition, No 1, New Haven, 1924.

[28] Manuscript on Skeletal Remains at Pecos, to be published in the same series as reference 24.

occupied at different times. We seem to have here a population curve in which the rise is explained by social and economic efficiencies and the fall by decreasing agricultural returns, by disease introduced by Europeans, and lastly by savage warfare intensified after the horse had made long raids possible.

SOUTH AMERICAN ARID-LAND CIVILIZATION

In South America the agricultural civilizations are more ancient in the arid and open regions of Colombia, Ecuador, Peru, etc., than in the wet forested regions of the Guianas and Brazil; but fluctuations and displacements of population are more marked in the wet country for reasons that are not far to seek.

The earlier series of Central American economic plants must have reached Peru during the Archaic period a thousand years or more

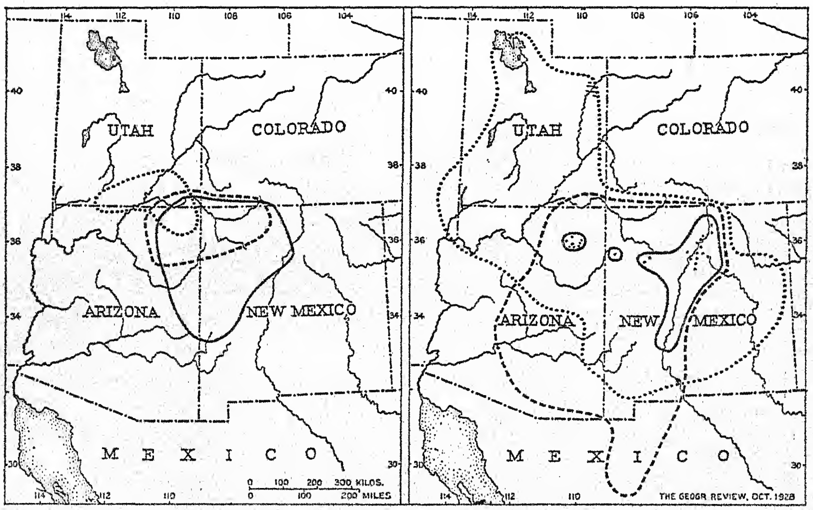


FIGURE 5.—Development of Pueblo culture. The left-hand map shows the nucleus of Pueblo culture; dotted line, region of Basket Maker II; dashed line, Basket Maker III; solid line, Pueblo I. The right-hand map shows the expansion and contraction of Pueblo culture; dotted line, Pueblo II; dashed line, Pueblo III; solid line, region occupied at the conquest; modern Pueblos are shown by dots

before the time of Christ. Under the fairly stable but inelastic conditions of desert-land farming a practical balance between population and food supply may well have been reached on the basis of these plants and maintained with little change for many centuries. One frequently hears the opinion expressed that the agricultural terraces, or *andenes*, of Peru indicate a greater population in the past than now exists. But these terraces are still used in rotation; and, while impressive monuments for conservation, they do not, in fact, retrieve much acreage.

There was on the Peruvian highlands a great use of the indigenous potato, which may have been gathered anciently as a wild root crop.

It is an important question whether the Andean tuber actually antedates maize, beans, and squashes in Peruvian cultivation; probably not, however, since the shell heaps of Ancon,[29] quite outside the natural habitat of the potato, nevertheless yield evidences of sedentary agricultural life earlier than proto-Nascan remains, likewise near the coast; and these in turn antedate the classical remains at Tiahuanaco on the plateau. The use of the potato extended from Chile into western Venezuela along the Andean ridges.

In spite of various shiftings in the centers of empire[30] the population of Peru seems to have maintained itself without cataclysmic breaks before the coming of the Spaniards. There were, to be sure, certain peaks of artistry which may or may not correspond to peaks of population. It is my opinion that extensions of civilizing influences from Central into South America will be found to correspond roughly with the Maya and Toltec culture crests, i. e. 400–600 A. D. and 1000–1200 A. D. The evidence of these streams of influence is seen more clearly in the wet-land cultures than the dry but may be noted in the art of Chavin and Recuay and more fully still at Puruhá in Ecuador.[31]

There is no reason to believe that the rapid growth of Inca power entailed great wastage of life. Indeed, the improved economic condition which followed the building of roads and the opening up of new provinces may actually have brought about an increase in numbers, at least making it easier to relieve famines. One thing is evident enough: The Peruvian conquests were made in regions where sedentary agricultural life had long since been established. Archeological stratifications in Ecuador[32] on the one hand and in Argentina[33] on the other prove this.

Perhaps density of population in the region covered by the Peruvian empire reached its apogee under Huayna Capac, the eleventh Inca (1470–1525). But the arrival of Pizarro in 1532, in conjunction with the fratricidal triumph of Atahualpa, was a stroke of doom. There was surely a tremendous falling off among the Indians of Peru after the Spanish occupation—the dire result of repressive measures,

[29] Max Uhle: Die Muschelhügel von Ancon, Peru, Proc. 18th Internatl. Congr. Americanists Held at London, 1912, pp. 22–45, 1913.

[30] See for instance P. A. Means: An Outline of the Culture-Sequence in the Andean Area, Proc. 19th Internatl. Congr. Americanists Held at Washington, Dec. 27–31, 1915, pp. 236–252, Washington, 1917.

J. C. Tello: Introducción a la historia antigua del Peru, Lima, 1922, and various papers in Inca, Lima, 1923—.

Stratigraphic and stylistic studies are among papers by A. L. Kroeber, W. D. Strong, Max Uhle, and A. H. Gayton in Univ. of California Publs. in Amer. Archaeol. and Ethnol., Vol. 21, Nos. 1–8, 1924–1927, and see also the paper on The Uhle Pottery Collection from Nasca, by A. H. Gayton and A. L. Kroeber, ibid., Vol. 24, No. 1, 1927.

[31] Jacinto Jijón y Caamaño: Puruhá, Bol. Acad. Nacl. de Hist. Quito, Vol. 3, 1922, and succeeding volumes.

[32] Jijón y Caamaño, op. cit.

[33] Éric Boman: Los ensayos de establecer una cronología prehispánica en la región Diaguita (República Argentina), Bol. Acad. Nacl. de Hist., Quito, Vol. 6, pp. 1–27, 1923.

slavery, starvation, and disease. The adjudication of numbers for an era of 1525, when the eleventh Inca died without knowledge of the coming collapse of his great empire, can not be made now; but it is not impossible that in many regions of Peru, Bolivia, and Equador the Indian has about retrieved his former situation as regards numbers.

SOUTH AMERICAN CENTERS OF WET-LAND CULTURE

These general observations on the stability of arid-land civilizations do not hold true of certain rather brilliant but restricted cultures of Colombia and Ecuador which flourished in humid lands and which had pretty clearly fallen into decay before the arrival of European marauders; nor do they hold true of ancient centers of wet-land civilization in Venezuela and Brazil, located farther to the east. In Colombia and Ecuador, I refer more especially to the Zenu, who occupied territory east of the Gulf of Uruba; to the Quimbaya,[34] who held the middle valley of the Cauca; to the nameless people who built the stone monuments of San Augustin [35] on the headwaters of the Magdalena; and to other tribes, whose very designations are doubtful but who once ruled the Pacific coast of Colombia and Ecuador from Choco to Manta. An outlying contemporary center was that of the Tairona on the flanks of the Santa Marta Mountains in eastern Colombia, recently described by Mason.[36]

These form an interesting chain of localities where the humid tropics were temporarily conquered after the manner of the Mayas. The economic and social interrelations of these localities are found on the historical levels of Mayan and especially Chorotegan developments, or safely within the Christian era. The special contribution of these South American States was in metal working according to a technique which was afterwards imitated in Mexico, namely, a kind of filigree jewelry made by the lost wax process. Since no examples of this jewelry or any other objects of metal occur at the First Empire sites of the Mayas, while numerous specimens, some being clearly of Colombian manufacture, are found in Northern Yucatan in deposits of about 1200 A. D., the conclusion is that the characteristic art of the southern centers flourished broadly from 500 to 1300 A. D. with activity in trading during the last two or three centuries of this period.

---

[34] Ernesto Restrepo Tirado: Los Quimbayas, a décimo octavo Congreso Internacional de Americanistas que se reunira en Londres en Mayo de 1912, Edicion oficial, 66 pp., Bogota, 1912.

Eduard Seler: Die Quimbaya und ihre Nachbarn, Gesammelte Ablandl., Berlin, Vol. 5, pp. 63–76, 1915. From Globus, Vol. 64, pp. 242–248, 1893.

[35] K. T. Preuss: Bericht über meine archäologischen und ethnologischen Forschungsreisen in Kolumbien, Zeitschr. für Ethnologie, Vol. 52–53, pp. 89–128, 1920–21. "Ausgrabungen in der Gegend von San Agustin" covers pp. 91–105.

Idem: Die Ausstrahlungen der San Augustin-Kultur in Amerika, Zeitschr. für Ethnologie, Vol. 59, pp. 111–112, 1927.

[36] J. Alden Mason: Archeological Researches in the Region of Santa Marta, Colombia, Compte-Rendu Congrès Internatl. des Américanistes, 21st Session, 2nd Part, at Göteburg, 1924, pp. 159–166, Göteburg Museum, 1925.

In addition to metal work there are other important intercontinental changes in technology and design, regarding which space does not permit elaboration. But the important bearing of these archeological indications is on the question of ancient population of the wet tropics below the intensively developed Mayan territory. For, if civilization had a long time to run in such environment, it must surely have resulted in dense settlements.

The best evidence that civilization did have a fairly long life in certain parts of humid South America is seen from the fact that a high culture existed about the mouth of the Amazon which had disappeared before the arrival of the whites. The archeological bond between Central America, Venezuela, and the lower Amazonas is first found on the Archaic level corresponding to an early distribution of the maize complex.[37] But eastern Brazil became the center of new agricultural developments. Manioc, sweet potatoes, pineapples, etc., seem to have been domesticated here and distributed towards the west. The high culture attributed to the Arawack and Tupi tribes was broken down by the raiding Caribs, and the beginning of the West Indian occupation may correspond roughly with the end of the Amazonian civilization. Some of the tribes moved out over the Antilles, and others pushed down along the coast of Brazil. But there are other evidences that the Amazonian use of jade and several religious concepts displayed in art must be placed at the earliest about 1000 A. D. This leaves, however, a long enough interval after the introduction of agriculture on the Archaic horizon to account for high populations.

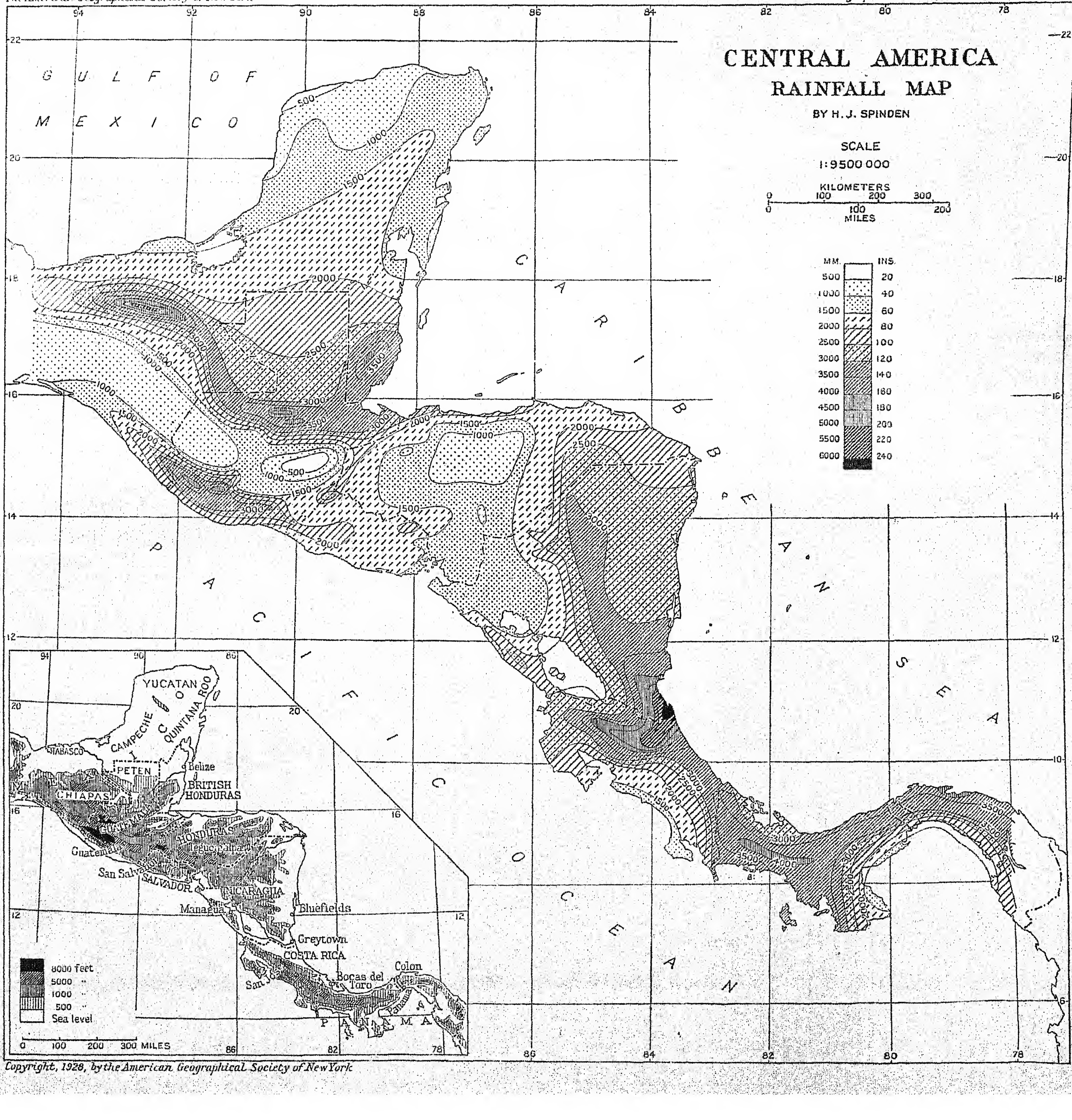
CONCLUSIONS

1. The present equivalent of the Indian blood in the New World is in excess of 25,000,000 individuals.
2. There are fewer Indians to-day than at the coming of Europeans.
3. Various ancient peaks are indicated by the archeological record in different parts of the New World. The first high population level was reached in Central America and Mexico during the First Empire of the Mayas (with greatest density about 550 A. D.), and a second one of much greater extent obtained during the florescence of the Toltecs.
4. The chronological evidence indicates the greatest aboriginal population of America about 1200 A. D., this being a halcyon epoch of far-flung trade at the maximum expansion of wet-land cultures. The numbers of the red race may then have amounted to two or three times the present numbers, or say 50,000,000 to 75,000,000 souls.

---

[37] Female fetishes of fertility reach from Mexico to the island of Marajo in the mouth of the Amazon. For a brief presentation of the evidence see my "Ancient Civilizations of Mexico and Central America," published as a handbook by the American Museum of Natural History, 3rd edition, 1928.

The American Geographical Society of New York The Geographical Review, Vol. XVIII, No. 4, 1928. Pl. VII



5. Fluctuations have been much more evident in humid lands, tropical or temporate, than in arid lands.

6. The greatest factor in depopulation has been disease in epidemic form.

NOTE ON THE RAINFALL MAP

In compiling this map use has been made of official statistics where available (including the United States Weather Bureau's West Indian and Caribbean Service, Oliver L. Fassig in charge) and standard references such as Hann's "Handbuch der Klimatologie" and Supan's "Die Verteilung des Niederschlags," Petermanns Mitt. Ergänzungsheft No. 124, 1898. Also of the following:

Alfred Merz: Beiträge zur Klimatologie und Hydrographie Mittelamerikas, Leipzig, 1907.

M. W. Harrington: Central American Rainfall, Bull. Philos. Soc. Washington, Vol. 13,1895–1899, pp. 1–30, Washington, 1900.

W. W. Reed: Climatological Data for Central America, Monthly Weather Rev., Vol. 51, pp. 133–141, Washington, 1923.

Paul Heidke: Regenmessungen aus Guatemala, Deutsche Übersee. Meteorol. Beobachtungen, No. 23, pp. A 26–30, Deutsche Seewarte, Hamburg, 1922.

Karl Sapper: Grundzüge der physikalischen Geographie von Guatemala, Petermanns Mitt. Ergänzungsheft No. 113, 1894.

Karl Sapper: Verteilungen des Regenfalls in nördlichen Mittelamerika (map). Petermanns Mitt., Vol. 43, Pl. 10, 1897.

Karl Sapper: Die Alta Verapaz (Guatemala), Mitt. Geogr. Gesell. in Hamburg, Vol. 17, pp. 78–214, 1901.

Eckhard Lottermoser: Die Ergebnisse der Temperatur-Beobachtungen in Salvador und Süd-Guatemala, Mitt. Geogr. Gesell. in Hamburg, Vol. 24, pp. 31–84, 1909.

Eckhard Lottermoser: Die Regenverhältnisse Mittelamerikas mit besonderer Berüksichtigung von Salvador und Süd-Guatemala, inang. Diss., Tübingen, 1911.

A. P. Davis: Hydrography of Nicaragua. Twentieth Ann. Rept. U. S. Geol. Survey, 1898–99, Part IV, Hydrography, pp. 563–637, Washington, 1900.

Rainfall records kept by commercial corporations and private individuals, mostly unpublished, including: records from the United Fruit Co. (Tela Railroad, Truxillo Railroad, etc.) in Guatemala, Honduras, Costa Rica, and Panama; the Cuyamel Fruit Co. (Cortes Development Co., etc.) in Honduras and Nicaragua; Vaccaro Brothers (Suiza Planting Co., etc.) in Honduras; Schlubach, Sapper & Co., Guatemala; Spencer Richardson, Las Cañas, Matagalpa, Nicaragua; from stations on the Salvador Railway Co.; from mines of Charles Butters, Salvador, Honduras, Nicaragua; and Minor C. Keith, Guatemala and Costa Rica, etc.

THE ABORIGINES OF THE ANCIENT ISLAND OF HISPANIOLA

By Herbert W. Krieger

United States National Museum

(With 27 plates)

HISTORICAL NOTES

The island of Hispaniola, anciently known as Haiti to its aboriginal inhabitants, is occupied jointly by the Dominican Republic and the Republic of Haiti. The island is the second largest of the West Indies and lies between the islands of Cuba and Jamaica on the west and Porto Rico on the east. Its area is approximately that of Ireland, and due to its varied topography a wide range of tropical climate prevails in different portions of the island. Broad valleys alternate with towering mountain ranges, culminating, in the Cibao, in Mount Tina with a reputed elevation of 3,140 meters.

The humid climate of the eastern valleys varies with almost sinister stretches of desert in the western third of the island. The lower Yuna River Valley in the east is a good example of dense tropical vegetation growing under humid climatic conditions, while the arid hills of the north central part of the island west of Santiago de los Caballeros mark the beginning of tropical thorn forests.

The northeastern part of the island is traversed from west to east by the Cordillera Setentrional which terminates on the west in the Silla de Caballo range near Monte Cristi on the north coast. Paralleling this range is the larger axial Cordillera Central known as the the Cibao. The fertile valley lying between these ranges extends from the Atlantic coast west of Monte Cristi to the Gulf of Samana on the east. It is drained by two of the largest rivers on the island, the Rio Yaque del Norte which empties itself into Manzanillo Bay on the north coast, and the Yuna River which flows eastward into Samana Bay.

Most of the cacao and tobacco grown in the island comes from the eastern portion of this valley, while farther west the valley is semiarid. The lower portion of this valley, or great central plain, anciently known as the Vega (meadow), was the most densely populated section

of the island before the conquest. A coastal plain extends back from the Caribbean as much as 50 miles along the entire southeastern coast almost to the Haitian border. Here are located several of the large sugar estates.

The north coast is largely given to the production of honey, while coffee is produced almost exclusively in the western portion of the island, which is occupied by the Republic of Haiti. Cattle raising has proved a profitable industry to the Spanish settlers of the interior uplands and semiarid areas of the west, but the greater part of the Dominican side of the island is still undeveloped. Tropical fruits, such as plantains, bananas, pineapples, coconuts, limes, lemons, and oranges, mangoes, breadfruit, and tropical root and tuber crops such as yams, sweet potatoes, yucca (cassava), yautia, and others, thrive in the more humid areas, where they have been introduced by aboriginal or European immigrants.

The first permanent settlement by Europeans in the New World is commonly said to be Isabela, on the north coast about 40 kilometers west of the city of Puerto Plata. This settlement, founded by Columbus in December, 1493, is really the second to be established in America, as a colony had been founded by Columbus near Cape Haitien, on the north coast of Haiti, a year earlier, shortly after one of his vessels had been wrecked on Christmas eve, 1492. Neither this earlier settlement, known as La Navidad, nor Isabela became permanent colonies, although Isabela continued to exist as the Spanish capital of the New World for seven years until it was voluntarily abandoned in favor of a settlement at the mouth of the Ozama River. This new settlement on the south coast had been established in 1496 because of its proximity to a newly discovered gold field. The present-day city of Santo Domingo, the capital of the Dominican Republic, developed from this settlement and is therefore entitled to the honor of being the first permanent settlement by Europeans in America. The unfortunate La Navidad colony was wiped out by the Indians within a few months of its establishment, under circumstances not definitely known. Its downfall was instigated by the Indian cacique of the Cibao, Caonabo, but was hastened by the dissolute conduct of the first colonists themselves.

The ruins of Isabela are still in existence and continue to arouse a romantic interest not shared by other outposts and colonies established by Columbus. Visitors have carried away much of the stone from the walls, and the destruction wrought by time is such that very little remains to make the site recognizable as the walled city it once was. In a letter to Washington Irving, published in 1859 in The Life and Voyages of Christopher Columbus, T. S. Heneken gives the following interesting description of the ruins as they existed nearly a century ago.

Isabela at the present day is quite overgrown with forest, in the midst of which are still to be seen partly standing, the pillars of the church, some remains of the king's storehouses, and part of the residence of Columbus, all built of hewn stone. The small fortress is also a prominent ruin; and a little north of it is a circular pillar about 10 feet high and as much in diameter, of solid masonry, nearly entire; which appears to have had a wooden gallery or battlement round the top for the convenience of room, and in the center of which was placed the flagstaff. Having discovered the remains of an iron clamp imbedded in the stone, which served to secure the flagstaff itself, I tore it out, and now consign to you this curious relic of the first foothold of civilization in the New World, after it has been exposed to the elements nearly 350 years.

This letter does not adequately describe the ruins as they exist to-day, when scarcely a stone remains in position on the walls, although the plan of the settlement is roughly visible in the piles of stones and the intervening forest growth. The site is readily accessible by automobile from Puerto Plata by way of Bajabonico and Blanco.

During his first voyage to the New World Columbus first heard of the island of Haiti while cruising westward along the north shore of Cuba. Lucayan Indians from the island of "Guanahani" (one of the Bahamas), where Columbus had first landed, accompanied him as interpreters and guides on the inter-island voyage which followed. As their speech was Arawakan, a language understood throughout the Bahamas and the Greater Antilles, their services were of great value. They informed Columbus that land existed on the southwest, northwest, and the southeast. They obviously referred to the islands of the Greater Antilles and to Florida.

Their repeated reference to a land lying to the east as being rich in gold influenced Columbus to turn about and to sail his caravels eastward. The high mountains of the island of Haiti were soon seen looming in the distance. The Lucayan guides now assured Columbus that the land sighted was inhabited by cannibals, while the land itself was referred to as Bohio, the meaning of which has been variously interpreted.

The island of Haiti was also referred to as Quisqueya—that is, the mainland. The native Arawakan term Aiti or Haiti, appears also to have been generally applied to the island by natives speaking the Arawak language. Haiti signifies mountainous country or high land, and in this sense the term was also applied to a subprovince of eastern Magua (a native province). The native name Cuba became Juana to the Spanish, and the island of Boriquen was renamed Porto Rico. Haiti gradually became known by the same name which the Spanish had given to their capital city, namely, Santo Domingo. Columbus had previously renamed the island Espanola. This term was later corrupted into Hispaniola. Modern practice is to again use the native term Haiti when referring to the entire island but to apply the term

Santo Domingo when referring to that portion of the island occupied by the Dominican Republic.

More than a month elapsed from the time that Columbus first landed at Cape St. Nicholas, the extreme northwestern point of Haiti, until he had completed exploration of the 400 miles of its northern coast and entered the Bay of Samana, in January, 1493. In the meantime one of his caravels, the *Santa Maria*, had been wrecked near Cape Haitien, and he had founded a settlement for the crew of his wrecked vessel near by, using wreckage from the ship as building material for the fort and storehouse. A large native village located a short distance inland from the scene of the shipwreck was the residence of Goacanagaric, the cacique of the northern province of Marien. Goacanagaric soon became the friendly adviser of Columbus and the lifelong friend of the Spanish invaders. The location of Goacanagaric's village, known by the name of Guarico, was but a short distance from the beach, where the village of Petit Anse now stands, about 2 miles southeast of Cape Haitien.

Goacanagaric told Columbus that Caribs had frequently made attacks on his people and had carried away captives. When on raiding expeditions, the Caribs were armed with bows and arrows. The offer of Columbus to protect the people of Goacanagaric from the invasions of the Caribs was enthusiastically received. Fear of the Caribs formed the basis of a lasting friendship between Goacanagaric and Columbus. At the island of Tortuga, not far off the Haitian coast and the village of Guarico, the Spanish had seen evidence of the presence of the roving Carib. Later, as Columbus sailed eastward and approached the Lesser Antilles, additional evidence was discovered of the presence of the Carib in Santo Domingo.

When Columbus with his two remaining ships, the *Pinta* and the *Niña*, rounded Cape Cabron and anchored in Samana Bay on January 13, 1493, he encountered Indians as hostile as the natives of the northwestern coast under Goacanagaric had been friendly. The captain of the *Pinta*, Martin Pinzon, had taken four native men and two girls from the vicinity of Porto Caballo on the northeastern coast aboard the *Pinta* to be sold later as slaves in Spain. When Columbus discovered what had been done he made restitution and returned the captives to their village with gifts, but the news of the capture had preceded them. The easily hostile Indians of northeastern Santo Domingo and of Samana Peninsula, known as Ciguayos because of their custom of not cutting their hair, simply anticipated a raid from the Spanish resembling that with which they were familiar from the Caribs.

Columbus thought that as the Ciguayans were hostile and appeared quite different from the peaceful subjects of his friend Goacanagaric of the northwest coast of the island, they must be representatives of

the dreaded Carib. An Indian was induced to come aboard the *Niña* where it was anchored in Samana Bay. This Indian intimated that the island of Carib (Porto Rico) lay to the east. Columbus gave several presents to the Indian, among which were two pieces of red and green cloth and some small glass beads, and sent him ashore. When approaching the shore in the ship's boat more than 50 armed Indians were discovered lurking in ambush in the thickets. The Indian who had been aboard the *Niña* persuaded them to come from ambush and to lay down their weapons, but they soon took alarm and showed fight. The boat's crew defended themselves and wounded two of the natives. This hostile encounter, the first armed conflict between Indians of the New World and Europeans, occurred on Sunday, January 14, 1493. The following day the Indians returned in large numbers with their cacique Mayobanex and his three attendants. Columbus invited them to lunch with him on honey and ship's biscuit. Mayobanex presented Columbus with a necklace of shell beads, and on his arrival at the ship Columbus gave him and his attendants red caps and bits of cloth and beads. When Mayobanex returned to his village on the north shore of Samana Peninsula near the mouth of the San Juan River, he sent to Columbus by messenger a "coronet" of gold.

Because of the hostile attack of the Ciguayan Indians with their bows and arrows, Columbus named the small bay where he lay at anchor the Bay of Arrows. Tradition places this bay a short distance east of the town of Santa Barbara de Samana, on the north shore of Samana Bay. The inlet is still called "Golfo de las Flechas" or the Bay of Arrows.

The costume of the Ciguayan Indians of Samana was negligible. The hair was worn long and tied in a tuft incased in a bag decorated with parrot feathers and hanging from the back of the head, giving an effect "as the women of Spain wear it." No mention is made in the literature of a headdress of feathers arranged vertically in the form of a half crown wherein each feather is attached at the base of the quill to a woven band, a form of feather headdress characteristic of the Carib and Arawak of Venezuela and Guiana.

Columbus took with him to Spain four young male Ciguayans who were to serve as guides to the islands occupied by the Caribs. The Ciguayans themselves have been called Caribs erroneously because of certain peculiarities in speech and dress. Their name of "Ciguay" applies to their custom of not cutting their hair, which contrasted with the practice observed by other Arawak groups on the island of Hispaniola who cut their hair. South American Arawaks, like the Ciguayans of Samana, did not cut their hair.

On his second voyage to the New World, Columbus again touched on the shores of the island of Hispaniola on November 12, of the same

year. He found the natives of southeastern Santo Domingo—that is, of the native Province of Higuey—as hostile as had been the Ciguayans, and, like them, also threatening to bind the Spanish with ropes. Also, at La Navidad, Columbus found two dead Spaniards bound with native ropes.

During his second voyage Columbus began the practice of sending natives of the island to Spain to be sold into slavery. Tribute was exacted from the remainder. The tribute was to be in gold, but an arroba of cotton—that is, 25 pounds—was later substituted as the amount of tribute to be collected quarterly from all adults over 14 years of age. As cotton was not grown throughout the islands, and as it was practically impossible to obtain gold elsewhere except in the central mountains of Cibao, service was accepted instead of gold or cotton. This was the beginning of the so-called repartimiento, later to be expanded into the encomienda system, under which natives of the conquered island were divided among the Spanish soldiery for administrative purposes, principally for the collecting of tribute. Under this arrangement the Indian population of the island rapidly declined. It is probable that to-day not one pure-blood descendant survives of the comparatively dense native population living on the island at the time of the discovery. The population at that time has been estimated at approximately 1,000,000. In the year 1507, according to Spanish records, 60,000 remained, while in 1533, 600 natives, supposed to constitute the remainder of the native population, were given lands at Boya. Jefferys writes there were but 100 natives still living in Haiti in 1730, but he estimates the number of survivors in 1550 as 4,000. To offset this rapid decline in workers for the mines and plantations, consignments of African slaves were brought to the island as early as 1508.

The island also gained an unsavory reputation from the fact that Spanish pirates used the island as a base and preyed on the French, Dutch, and British shipping. The long speedy boats used in this piracy were called fly-bote or freibote and their crews were known as freiboters, freebooters, or filibusters. The French and British united to suppress these pirates or freebooters and established a base on St. Christopher Island and later on the island of Tortuga, a small island north of Cape Haitien, Haiti. Frequent incursions were made into the northern parts of Haiti for the purpose of killing cattle. Those engaged in this activity became known as buccaneers, from boucan, the spit on which they cooked their meat.

From Tortuga, the French gained a permanent foothold on the western end of the island, now the Republic of Haiti. The activities of the French in bringing slaves from Africa soon exceeded the Spanish; their methods became harsher and more exacting than those of the easy-going Spanish planters on the Santo Domingo, or eastern side of

the island. To-day the population of the Dominican Republic which occupies the eastern three-fourths of the island, the territory once held by the Spanish, is estimated at somewhat less than a million with no color line drawn between the descendants of former Spanish colonists or slaves. Haiti, as a republic, occupies the western end of the island and has a population of nearly 3,000,000. The French element formerly present in this so-called "Black Republic" has entirely vanished.

BIBLIOGRAPHICAL NOTES

Bartholomew de Las Casas is the apostle of the decline of the native population and the principal accuser of Spanish misrule. Of all his numerous writings, the two most important for the study of West Indian ethnology are the Historia General and the Historia Apologetica de las Indias. Las Casas tells us that he began this latter work in 1527 while living in the Dominican monastery near Puerto Plata.

The several publications of the Hakluyt Society are useful in studying early historical contacts as well as the ethnology of the historic tribes. Select Letters of Christopher Columbus were published by the society in 1847; included is the famous letter of Doctor Chança describing the second voyage of Columbus. Girolamo Benzoni's History of the New World was translated and published by the Hakluyt Society in 1857. The ethnological observations of Benzoni are first-hand, as he spent 14 years in Haiti, beginning in 1541. Benzoni lived the simple life while in Haiti even to the extent of making his own cassava bread. The Journal of the First Voyage of Christopher Columbus, published by the Hakluyt Society in English in 1893, gives a detailed first-hand account of the admiral's contacts with the natives of Haiti. This work and the narrative of Ferdinand Columbus written in the nature of a biography of Christopher Columbus are particularly useful with regard to the study of the ethnology of the island at the time of the discovery.

The narratives collected in Churchhill's Voyages and Travels include a unique and excellent description of the religious life, magical practices, traditions, and social life of the Indians of the Vega, or great central valley, and of the Ciguayans of the northern Cordillera. This monograph was written by Friar Ramon Pane, a Franciscan monk who accompanied Columbus on his second voyage and was detailed by him to describe native religious and ceremonial life.

Peter Martyr's Eight Decades, or De Orbe Novo, is best available in Francis Augustus MacNutt's translation from the Latin and appears in two volumes. The first Decade was published in 1511 and is drawn from accounts and observations of Andreas Moralis, who had been sent by Governor Ovando, the second successor of Columbus as governor of the island, to explore the interior. Much of Martyr's work is pure gossip, for he admits that everyone who had been to the

Indies visited him. So far as he follows Moralis, Martyr's account appears to be authentic.

The Natural History of the Indies, published by Oviedo in 1526, is perhaps cited more frequently than any other work pertaining to early history and ethnology of Haiti and Santo Domingo. Oviedo lived in Santo Domingo shortly after Moralis explored the interior of the island. A French edition of Oviedo's work was published in Paris in 1556. Jefferys in his Natural and Civil History, published in London in the year 1760, follows Oviedo's description of aboriginal customs. Another borrower from Oviedo is Charlevoix, whose Historia de l'Isle Espagnole appeared in 1730. Charlevoix's map of the island of Haiti showing the location of the country occupied by the several aboriginal groups and giving the names of the various caciques is particularly useful.

EARLY TRAVEL AND TRADE ROUTES

The West Indian archipelago extends from Florida to South America in the form of a crescent, a distance of 1,600 miles. The northern islands of this archipelago were known as the Lucayan Islands to the aboriginal Arawak population. These islands are now known as the Bahamas. They are built up of a low-lying coralline formation like that of Florida, which is but 60 miles distant from the nearest island of the group. Yucatan Peninsula is twice that distance from the western end of Cuba. On the South American end, one of the islands known as the Lesser Antilles, namely Grenada, is 80 miles from Trinidad, which lies just off the coast of Venezuela. At neither of its outlying points, therefore, are the West Indies at all remote from the continental mainland of North or South America. The physical basis for the early culture and tribal migrations in the West Indies lies in the proximity of island land masses, also in the favorable northwesterly currents in the Caribbean.

The delta of the Orinoco River empties itself into the Gulf of Paria on the Venezuelan coast, which is in part inclosed by the large island of Trinidad. Tobago, of the Lesser Antilles, is separated from Trinidad by only 25 miles of water. The Orinoco discharges its water through 20 distributaries covering 160 miles of South American coast directly facing the Lesser Antilles. It is therefore likely that a South American canoe culture, developed by the coast Carib and Arawak groups, reached the Greater Antilles by way of the smaller and more proximate Lesser Antilles. Dislodged groups followed the outgoing current of the Orinoco in their dugout canoes, paddled their way along the leeward side of the island chain, and gradually approached the large islands of Porto Rico, Haiti, Cuba, and perhaps Jamaica. In this northwestward migration wind and ocean currents were favorable factors.

After leaving the South American coast, when returning to Santo Domingo on his third voyage, Columbus discovered the strong westerly direction of the Caribbean current. Lying to at night, as he feared he might strike shoal water or reefs if he engaged in night sailing, he found to his dismay that the drift to the northwest was astonishing. Even when making allowance for this westerly drift, he first sighted the Dominican coast near the island of Beata, 150 miles west of the mouth of the Ozama River and the city of Santo Domingo, which he had desired to approach direct.

A recent study of shell heaps and kitchen middens on the islands of Aruba, Curaçao, and Bonaire, by De Jong, discloses strong confirmatory evidence of direct culture migration between these islands, which lie just off the Venezuelan coast of South America, and Santo Domingo. Kitchen middens, recently excavated in the Silla de Caballo Mountains of northern Santo Domingo, revealed literally thousands of objects more or less fragmentary but astonishingly similar to those described by De Jong from Curaçao. It is possible that some of the early culture diffusion from the South American mainland to the Antilles, particularly to the island of Jamaica, was along this direct route.

Columbus found the Lesser Antilles in possession of the Carib Indians. They had but recently displaced an earlier Arawakan group and perhaps one or two other, more primitive, nonagricultural peoples like the Ciboney of Haiti and Cuba. The warlike characteristics of the Carib contrasted strongly with the peaceful Arawak, who were primarily tillers of the soil. It is evident, though as yet not clearly demonstrated, that the lacustrine and maritime tribes, who were occupied principally with fishing and hunting, and who were in possession of the Lesser and Greater Antilles even before the arrival of the Arawaks, are to be identified with the prehistoric and historic tribes of identical culture who occupied the Gulf and Caribbean littoral respectively of North and of South America. An example of this primitive culture group is the Warrau, a coast tribe occupying the delta of the Orinoco River and related linguistically neither to the Awawak nor to the Carib, who occupied the bulk of the Guiana coast of South America southeast of Venezuela and who ranged far into the interior of the South American Continent.

At the time of the discovery, Indian sailors ventured into the open waters of the Atlantic and the Caribbean in their dugout canoes. These canoes varied in size, but each possessed the common quality of having been cut from a single tree trunk. Columbus wrote that "the dugout canoes of Haiti were of solid wood, narrow, and not unlike our double-banked boats in length and shape, but swifter." Caribs of the Lesser Antilles were in the habit of sailing to Porto Rico to

obtain boat building material, as the trees growing in the Lesser Antilles were not suitable for canoes. Carib raiders were engaged in raiding the north coast of Hispaniola in search for Arawak victims for their cannibalistic practices, but also for Arawak women, whom they took with them into captivity. Mona Passage separating Porto Rico from Santo Domingo was frequently crossed by Arawak sailors, Mona Island, in mid-channel, affording a convenient shelter.

Fire-killed trees were felled by firing. The trunks were gouged out with beveled shell celts or with stone axes after alternate processes of burning and charring to loosen the wooden fiber to be removed. The width of beam was increased by inserting thwarts or transverse beams of wood. A unique invention was the building up of the gunwales with a plaited bulwark of sticks and reeds knitted together with vines and pitched with gum. Herrera describes the canoes as "boats made of one piece of timber, square at the ends like trays, deeper than the canoes, the sides raised with canes, daubed over with bitumen." Use of cotton sails and awnings, decorative designs in paint and carving, all were traits making the West Indian dugout canoe a highly developed invention. Paddles rather than sails were the ordinary means of propulsion. A long paddle having a crutch-shape handle was generally employed. Long voyages were not infrequent. For instance, three Lucayan Islanders escaped from Santo Domingo and the bonds of Spanish slavery and attempted to sail back to the Bahamas. They were recaptured when they had practically completed their journey of more than 100 miles. Bailing was accomplished with a calabash; also by rocking the boat.

The large native vessel, supposedly Mayan, encountered by Columbus during his fourth voyage, when off the coast of Guatemala, was engaged in a trading expedition, but no adequate evidence has ever been presented that such trading vessels from the Central American mainland ever reached the coast of Santo Domingo or even Cuba, or that materials such as it carried for trading purposes ever were seen by Spanish explorers in the Greater Antilles. Neither were aboriginal Jamaicans willing to sail their canoes northward across the strong Caribbean current to the southern coast of Santo Domingo. A single Indian was picked up by Columbus during his first voyage while sailing from Tortuga Island to the northern coast of Haiti, a comparatively short distance.

Another instance or two might be cited from the Journal of Columbus. During his first voyage he found individual Indians paddling their dugout canoes from one of the Lucayan Islands to the other. For provisions such sailors carried cassava bread and a calabash of water.

CULTURE DIFFUSION IN THE WEST INDIES

The connection of the island Arawak with the tribes of Florida was essentially one of trade and provisioning. Transference of decorative designs, therefore, was incidental to trade contracts. Peter Martyr mentions a species of tree in the Lucayan Islands where many pigeons nest. Indians from Florida came to catch these pigeons and carried boatloads back with them. In Guanahani, the Indians knew of a land lying northwest of the Bahamas; also in Cuba, natives knew of a land mass on the north. Just what relationship existed in the making of coonti flour in native Florida and of cassava flour in the Greater Antilles remains uncertain. Methods employed in the production of the root flour are similar and the stages of bread manufacture are somewhat parallel. In Florida, roots of several varieties (*Zamia floridiana*, and *Smilax*, sp.) were chopped, pounded, and washed. Here, however, the fact must be recorded that while in Florida the washing was done to extract the desirable portions of the roots, washing of the cassava (*Manihot edulis*) was necessary to remove the undesirable or poisonous portions of the roots.

Doctor Swanton, on the authority of linguistic relationship, suggests that the sweet potato may have been introduced from the West Indies. It is probable, however, that both maize and sweet potatoes were cultivated on the mainland of both North America and South America before any direct culture or tribal migration occurred between the West Indies and Florida. Hernando Fontaneda, a Spaniard who was wrecked on the Florida coast and captured by the Calusa Indians, lived with them from 1552 to 1560. He is authority for the statement that Indians from Cuba used to come to Florida searching for the mythical fountain of youth. These Indians came in such numbers that the chief Caloosa assigned them a particular village in which they might live, at the same time informing them their quest was useless. We do not know the location of this village. This account of a village of Cuban Arawak immigrants living in Calusa territory in southwestern Florida is, indeed, recent enough to be historical, although the migration may have been prehistoric. In general, the culture of the island Arawak, and Caribs as well, is South American in origin and, in a general way, in content, while the Floridian tribes, including the Calusa, were influenced from the north far more than they ever were from casual or even regular trading contacts with the Antillean aborigines.

It is in agriculture that the essentially South American culture elements reappear throughout the native provinces of Haiti. Relationship of the historical tribes is with the agricultural peoples of the tropical lowlands of Venezuela and Guiana. Antillean tribes had retained or borrowed the elements of cassava culture from tribes of

northeast South America where it continues characteristic of the area. The making of bread from the yucca or cassava root (*Manihot edulis*), and the production of vinegar from its juices, used as a seasoning for the pepper pot, was introduced from South American lowlands. In the West Indies the culture of the yucca was subjected to environmental changes. The extensive use of maize in Santo Domingo supplies, however, evidence of a culture influence from the upland areas of Colombia and regions west of the tropical lowlands of Venezuela. The absence of active trade with Yucatan and with Mexico at the time of the discovery is evidence that theories of Mexican influences of a direct nature may be entirely discarded.

Pottery was brought to the Greater Antilles and there developed into artistic forms not known in the pristine home of the island Arawak. Stoneworking became especially developed in Porto Rico and in Haiti and in certain of the islands of the Lesser Antilles where suitable stone for working was to be obtained. This art, however, appears not to spring from any South American focus of Arawak culture. It is rather a special growth, strangely parallel with Mexican and Central American examples. The same observation may be made with regard to decorative forms in pottery. It is probable that tropical South America in its eastern lowland reaches and the Antilles each received their original culture impulse from Central American sources by way of Colombia; but the West Indies, not being repressive areas like the overpowering forests of South America, witnessed a local development in agriculture, pottery, and in stoneworking surpassing that of the tribes remaining in Venezuelan and related land areas.

Culture development in the Greater Antilles does not express itself so much in an additional number of culture elements as in local embellishments of form. This is especially noticeable in pottery and in the sculptor's arts as applied to religious motives. It is possible, too, that Cuba, Haiti, and Porto Rico were subjected to influences in pottery production from North America. The hand-molded anthropomorphic and zoomorphic heads and figurines in clay are essentially West Indian in form but Central American in origin, their nearest prototypes being the anthropomorphic figurines on ancient unpainted ware from Panama. Unpainted archaic pottery was brought with the island Arawak from South America and many later developments have stimulated the production of pottery in the Antilles along original lines embodying new forms.

Griddles of earthenware for baking cassava are South American, even with regard to their circular slightly concave form, while the typical North American stone mortar (metate) for the grinding of corn is greatly modified in the West Indian culture complex. A tendency toward a conventionalized treatment of realistic models of

animals and bird heads indicates presumably a long period of isolated development of forms and shaping technic.

The presence of closed stone collars within the areas of the Antilles and Central America, also the manufacture of stools of stone with sculptured anthropomorphic and zoomorphic figurine carvings, the presence of axially drilled tubular stone beads, the weaving of cotton cloth, the wearing of a woman's garment similar to Central American patterns, and, above all, the molding of archaic clay figurines in anthropomorphic and zoomorphic designs—all these indicate a remote influence from Central America entirely distinct from a more direct Mayan influence from Yucatan, which apparently did not occur. If connection had existed with the Mayan area, artifacts from western Cuba would have revealed such connection. It must not be overlooked, however, that maize and cotton were two important culture plants in Yucatan as in Cuba and Santo Domingo. Cotton yarns and cotton cloth entered native trade extensively in the Greater Antilles and cotton products were some of the first objects offered the Spanish in trade for the much coveted hawk's bells which were made of a copper alloy. Guarionex, cacique of the Magua Province (Vega), offered to plant cornfields extending from one end of the great central valley to the other, that is, from sea to sea, and to present the harvested crops to the Spanish as tribute in lieu of gold. Cotton was also extensively grown, if we are to believe the statement that an arroba, or 25 pounds of cotton, could be collected as tribute from each adult at periodic intervals.

HISTORICAL DISTRIBUTION OF NATIVE POPULATION

At the time of the discovery the Arawak Indians of Haiti and Santo Domingo were grouped in more or less well-defined geographical areas under rulers locally known to the aborigines as caciques. There were caciques of many degrees of social and political influence, varying in power according to their functions and the number of villages under their control. Caciques were the leaders and advisers of their people and appear to have united political, social, and religious leadership under one head. Some of the lesser caciques were merely medicine men or shamans; others wielded a powerful sway over large sections of the island. There were five principal native provinces, each under the control of a cacique, who controlled in turn many lesser caciques. The cacique over a village ordered the routine of daily life and assigned to individuals such duties as pertained to communal hunting, fishing, and tillage of the soil; they also presided at religious ceremonies. The cacique of a Province appears to have been a "rex inter pares" with magnified powers in time of danger or war. Fewkes says that "as a rule each village seems to have had a chieftain or patriarchal head of the clans composing it, whose house was larger than the other

houses and contained the idols belonging to the families. In addition to the household of the cacique, consisting of his wives and immediate relations, a prehistoric village ordinarily contained also men, women, and children of more distant kinship."

Of the five leading caciques at the time of the discovery only one, Goacanagaric, who ruled over the Province of Marien, on the north coast, west of the Rio Yaque del Norte, remained friendly toward the Spanish. Marien extended from Cape Nicolas, on the extreme northwest, to the vicinity of Monte Cristi at the mouth of the Yaque River. The Province extended inland to the arid regions of the headwaters of the upper Yaque and the southern slopes of the Cordillera Setentrional.

The "inland empire" of the island, the great central plain traversed by the Yaque and Yuna Rivers, known as the Province of Magua, was under the cacique Guarionex. This Province included the central and best portions of the Cibao Valley, the so-called Vega Real, also the southern alope of the Cordillera Setentrional. On the south the Province was bounded by the Cordillera Central. The Valley of the Cibao, the "Vega Real," was the most densely populated region of aboriginal Haiti. The deep loamy soil received ample rainfall and facilitated an intensive development of agriculture. The interior section of the valley has two periods of heavy rainfall, one in November, the other in the spring. The western portion of the great central plain is arid and thorn forests begin west of the present-day interior town of Santiago de los Cabelleros. On the north coast, the Province of Magua extended as far west as Monte Cristi, while in the mountains of the north it was joined by the territory of the Ciguayans.

Maguana included the central mountains, the Cordillera Central, and the lands along the south coast of the island from the Ozama River to the lake region in Azua, near the present Haitian-Dominican boundary. This Province included the valley of the Artibonite (Hattibonito) River and included generally some of the most fertile lands of the Cibao. It was from this Province that came rumors of gold mines so rich as to arouse the passion of the Spanish colonists. The cacique at the time of the discovery was Caonabo, an immigrant from the island of Carib (Porto Rico), as it was known to the aborigines.

Xaragua Province formed the southwestern Province of the island. It was bounded on the north in part by Maguana and Marien, and on the east by Maguana. It included most of the western coast with the projecting southwestern peninsula. The inner side of the Gulf of Xaragua, now known as the Gulf of Gonaive, and the surrounding dry flat land were developed on an extensive scale through the construction of irrigation canals. Cotton was produced in comparatively large quantities, considering the relatively unclothed condition

of the natives. Xaragua was considered by the Spanish the richest and best-developed native Province of the island. Its cacique at the time of the discovery was Behechio, who, with his sister Anacaona, offered to pay the tribute exacted in produce instead of gold. Anacaona was the widow of the cacique Caonabo, who died a prisoner of the Spanish on board a vessel taking him to Spain for trial for insurrection against Spanish rule, also for instigating the uprising against the colony at La Navidad.

After the death of Behechio his sister, Anacaona, inherited the right to govern the Province of Xaragua. On one occasion when the Lord Lieutenant (Adelantado) Bartholomew, the brother of Columbus, visited the town where these caciques resided, he was presented with 14 carved wooden seats (duhos), 60 earthenware vessels, and 4 rolls of woven cotton. Cassava bread in sufficient quantity to relieve the hunger of the Spanish then in the island was supplied and a small vessel was filled with the gifts of these Indian rulers.

The term Guaccairima was sometimes applied to Xaragua and referred principally to the southwestern peninsula. Gonave Island, situated a few miles from the west coast, was noted for the excellence of its native wood carving, and the islanders carried on a trade with the Indian villages of the Haitian mainland.

The native Province of Higuey in southeastern Santo Domingo offers difficulty in the defining of its aboriginal boundaries. It probably included all of southeastern Haiti south of the Bay of Samana, the Yuna River, and the Cordillera Central, and east of the Ozama River. In his De Orbe Novo, Peter Martyr names the eastern Province of Higuey with the term Caizimu which is supposed to have extended from Cape Engano on the east to the capital city, Santo Domingo, on the southeast. The northern border of this province of Martyr's was marked by precipitous mountains which on account of their steepness bore the name of Haiti. An interesting observation regarding Martyr's classification of native Provinces is that he agrees with other early Spanish chroniclers in placing Xamana (Samana) as a subprovince within the Province of Huhabo (Magua) and not as a subprovince of Caizimu (Higuey). He also agrees with other less verbose writers in saying that the language of Huhabo, that is, of Magua which included Samana, differed from that spoken elsewhere in the island.

Las Casas speaks of Cotubanama as cacique of Higuey Province. Other writers, referring to periods subsequent to the decade of the discovery, speak of Cayacoa and of the female cacique Higuanama.

In giving this historical reference to tribal and provincial groupings for the period following the discovery, which is drawn from the literature of the day, it is not assumed that a static condition of affairs existed throughout the island. Personal ascendancy of

strong characters such as the cacique Caonabo, and the increase or decrease of population in different parts of the island served to make social and political conditions subject to sudden change. It is to be assumed that the influence of the warlike Caribs and the introduction of new weapons which they brought with them were added factors making for social change. Improvements in native agriculture, as irrigation in Xaragua, and the growing of maize in the Vega accelerated culture advance on the part of sedentary agriculturists. Differences in speech easily developed between the hunters living in the mountains, as the Ciguayans of Samana Peninsula and of the Cordillera Setentrional on the one hand, and the subjects of Guarionex who lived by agriculture in the Cibao Valley. The Ciguayans were a mountain folk and spoke a dialect not readily understood by the valley folk. The historical method of collecting observations of contemporary Spanish writers must be supplemented with archeological studies of cultural remains to arrive at any understanding of culture sequence on the island. Archeological methods alone can explain the many crude artifacts of stone, shell, or bone embedded in middens throughout the island as being either pre-Arawak or as belonging to an early stage of Arawak culture antedating the development of agriculture.

Within historic times the aboriginal population of the West Indies has included two linguistic stocks, the Carib and the Arawak. The Arawak were in possession of the entire island of Haiti but differed remarkably in their culture activities in various parts. The Caribs were encroaching on Arawakan settlements along the north coast, but had never penetrated the interior. How long a period of occupancy by the Arawak had elapsed prior to the advent of the Spanish remains an unsolved problem. A still more engrossing problem is the question of a pre-Arawakan population.

That the Arawak population had been preceded by an earlier less-developed folk culturally has been reported by Spanish writers and is confirmed apparently by archeological excavations on Cuba and Haiti. Vague reports by Las Casas, Oviedo, and others tell of a primitive people existing in southwestern Haiti. Moralis wrote that in the mountains of western Haiti there existed wild men without fixed abode, without a language (sic), and not given to the practice of agriculture. Oviedo wrote that a cave population in western Haiti was not subdued until 1504. The researches of William Gabb in 1869–1871 in the vicinity of Samana Bay appear to establish the presence of culture stratification in certain caves. This discovery was verified and amplified by expeditions from the United States National Museum in 1928 and 1929, but the question is still unsolved as to whether this stratification reveals a pre-Arawak population as having frequented the caves, or whether it merely points to a rather marked

local variation within the Arawak culture horizon from the standpoint of time sequence and culture lag.

Martyr wrote in his De Orbe Novo that a cave population similar to the Guanahatabeyes, "Ciboneys," also mentioned by Velasquez, had lived on the southwestern peninsula of Haiti. Martyr relates that "it is said there is a savanna district in the most westerly Province of Guaccairima (Xaragua) inhabited by people who only live in caverns and eat nothing but the products of the forest. They have never been civilized nor had any intercourse with any other races of men. They live, so it is said, as people did in the golden age, without fixed homes or crops or culture; neither do they have a definite language. They are seen from time to time, but it has never been possible to capture one, for if, whenever they come they see anybody other than natives approaching them, they escape with the celerity of a deer." Las Casas lived in the villages of the extreme southwestern portion of the island in the Province of Xaragua. He did not see the cave dwellers described by other writers, but reported the population of Xaragua (the present Haitian Province of Jeremie) as resembling in its culture the Higuey Indians of Santo Domingo. He mentions the Ciboneys as being a primitive group living in the mountains of the interior and as not given to the practice of agriculture as were the natives of the central valleys and coastal plains.

It is possible that Arawak immigrants had subjugated these earlier people. Las Casas believed this to be the case when he wrote, referring, however, to the natives of Cuba, that the "servants subjugated by the invaders from Haiti were known as Ciboneyes." These Ciboneyes of western Cuba spoke a language that Columbus's interpreters from the Lucayan Islands could not understand.

Caves were used by the island Arawak, however, for various purposes such as temporary dwelling places, as ceremonial chambers for expression of religious cult, as burial vaults, and for shelter from their enemies, also doubtless for several other purposes. Spanish writers observed that fishermen occupying the small islands off the coasts of Cuba and Haiti were subjects of the superior Taino (Arawak) but that they did not live in caves.

HABITATIONS

The dwellings of the aboriginal Haitians resemble those of the more highly developed tribes of tropical South America. The dwellings of the Seminole Indians of Florida, also those of the Florida key fishing tribes, were of the same type and were not like the pile dwellings of the Warrau of the Orinoco River delta, which represent a more specialized building technic. Isolated remains of pile dwellings have been recovered in Cuba by Cosculluela and on Key Marco, Florida, by Cushing.

Natives of Haiti developed two types of house architecture. In one type a circle of poles was forced into the earth, each pole separated from the others by intervals of a meter or two. Between these poles were lashed split grommets of lianas covered perhaps with palm spathes as in the modern Dominican country habitation. Transverse beams resting on the upright poles supported the roof beams which converged to a conical peak. A thatch of grass or palm spathe rested on transverse slats covering the converging rafters. A center pole extended from the apex of the roof to the center of the floor of the hut.

A larger type of structure was the rectangular habitation of the cacique constructed of the same materials. Instead of a conical roof, a ridgepole extended from one end of the roof to the other. A lean-to extended from the roof of the main structure in the form of an open porch, such as may still be seen in country districts. No record exists in the literature of wattled mud walls such as are built in the arid sections of northern Santo Domingo and in Haiti.

The furniture of a native hut was meager. Domestic requirements came first and included earthenware vessels, calabashes, cassava working implements, perhaps also grinding stones for triturating maize, earthenware griddles for baking bread, seats of carved wood rarely, but always the hammocks of woven cotton. The hammock was chair, bed, couch, and cradle as well. Hammocks were slung out of doors on the porch. In colder weather they were slung inside the house, while a fire was kindled underneath. Sleeping on the ground was also common, for which an improvised bed of plantain leaves was prepared. Hammocks were of two kinds. The woven hammock was essentially a piece of woven cotton cloth, while the netted hammock had a framework to hold open the looped netting.

Duhos or seats of carved wood were graded according to the rank of the user. Important men sat on artistically carved wooden stools. Stools of stone and those of carved wood were to be found in the houses of caciques. Simple wooden stools were of the generalized South and Central American type in which a concave seat, provided with four short legs were cut from the solid. A step beyond this and still a common form was the concave undecorated seat with an anthropomorphic or zoomorphic figurine carved from the front end of the seat, while a stumpy tail projected from the rear or was entirely lacking. The elaborately carved, paneled, and inlaid seat with an arched tail section or back rest and elaborate head carving was reserved for ceremonial use at religious festivals. The legged stone seats with concave backs resemble a form of mealing stones, although the latter has a larger surface but has only three legs, while the much smaller seats of stone have four stumpy legs. The mealing stone here described had, like the stone seat, figurine heads

similar to those from Costa Rica. No data exists for comparison regarding the construction of seats from the Venezuelan coast or from Paria.

WEAPONS

Bows used by the Arawak of Santo Domingo and of Haiti were like those of the Carib, in that they were very long and fashioned from the heartwood. Their clubs were like those from the Guiana coast of South America, having a truncated, bulbous end section, while the entire weapon was polished. Their method of fighting with ropes resembles that of the Velez of Colombia. The custom of binding prisoners with ropes was general throughout the island.

When Columbus landed at Guanahani he found the inhabitants armed with wooden spears, the tips of which were hardened in the fire or tipped with the spine or tooth of a fish. Similar weapons were used by the Haitians. Although bows and arrows were in general use throughout aboriginal Haiti at the time of the discovery, no bows were found by the Spanish in Cuba, Jamaica, or in the Bahama Islands. Slender reed arrows were fashioned with a hardwood foreshaft tipped with a fishbone or bone splinter. There appears to have been no general use of poison by the natives of Haiti, although the Ciguayans of northeastern Santo Domingo and the natives of Higuey in southeast Santo Domingo dipped their arrows in a vegetable poison from the sap of the manzanillo tree (*Hippomane mancinella*).

Frequent mention is made in the literature regarding native use of darts with reed shafts and fire-hardened wooden points. No mention is made, however, of spear or dart throwers. No record exists of their recovery through archeological methods. It must therefore be assumed that the spear thrower like the blow gun was unknown and foreign to the weapon complex of the island Arawak. The "dart" and the fire-hardened javelin are apparently one and the same weapon although somewhat differently described by different Spanish observers.

A variety of the war club was the heavy sword club "macana" of the Haitian aborigines. The weapon was of heavy hardwood, flat and blunted at the edges. It was said to be more than an inch in thickness throughout.

No defensive weapons or armor were used north of the Venezuelan coast. Columbus saw a native canoe off the coast of Trinidad, the crew of which were armed with bows and were in possession of shields. Trinidad, however, lies close to the mainland of South America and the obvious conclusion is that the shield had not yet advanced beyond the island of Trinidad, while the Carib had already introduced the bow into Porto Rico and eastern Haiti.

FOOD RESOURCES, AGRICULTURE, HUNTING, AND FISHING

Food supply of the natives varied in accordance with the food-collecting habits of the various groups. Investigations by the writer of this article established a wide range of food resources for the several sites explored and kitchen middens excavated. The former occupants of the caves on the south shore of Samana Bay were primarily collectors of shellfish, snakes, rodents, fish, bats, worms, birds, or whatever natural produce came to hand, while kitchen middens at the sites of former open villages revealed a greater abundance of bird, fish, and animal bones. The small variety of conch known as the *Strombus pugilis* Linnaeus and the mandibles of several varieties of crabs were most frequent in the cave deposits, which in several instances reach a depth of 9 feet in those portions of the caves, usually near the entrances, which were obviously devoted to culinary purposes. Small mammal and turtle bones along with much other fragmentary evidence of aboriginal food resources, such as shellfish, predominate in the middens near the sites of former habitations.

Dr. W. L. Abbott found a species of small mammal, a jutia (*Plagiodontia hylaeum*) still living in the forested lowlands of the south shore of Samana Bay, near Jovero, although the several forms of small mammal life still in existence at the time of the discovery in Haiti and in Santo Domingo soon became practically extinct after the arrival of the Spanish, the disruption of native culture, and the introduction of slavery.

In general, it may be asserted that fishing rather than hunting was the chief ally of native agriculture along the coast, while in the interior agriculture alone supplied the staple food resources. Large plantations of food crops were observed at the time of the discovery in the drier areas where irrigation was utilized. Planting of calabash and fruit trees was extensive.

Benzoni in his History of the New World says that bread was made from maize and from cassava (yucca). Women wet the grain in the evening with cold water. The following morning the grain was triturated between two stones. The resulting meal was mixed or kneaded with water, and then shaped into round or oblong loaves. The loaves were then placed on flat or concave earthenware griddles and baked. This bread was supposed to be eaten while fresh. Another form of bread was made by cooking finely triturated corn meal, shaped into small loaves, in a pipkin over a slow fire. The Spanish loathed cassava bread but were compelled to eat it as the cultivation of maize was limited.

Benzoni's statements relative to maize culture in Haiti are explicit. The ground was not otherwise prepared for planting except by burning off the forest growth and then planting corn in the ashes. A small hole was made in the soil, three or four grains inserted, and

covered over. Planting was repeated during the year in favored locations. Irrigation was resorted to in Xaragua, where trenches have been observed.

The digging stick was used in planting maize. The soaked kernels to be sown were carried suspended from the neck in a woven bag. The Arawak farmer made his plantings in a cleared field in the forest. The savannas were unavailable because of the grasses and tangled root masses which would smother the newly planted crop.

Like the cassava, yams and sweet potatoes were cultivated in mounds while maize was grown in hills separated by the distance of a pace.

Hunting was limited by the absence of large mammals. Jutias were hunted by burning the grass to drive them out. Communal drives were organized in the dry season. Clubs were used as hunting weapons, and the small dumb dog was employed. These dogs themselves were eaten and considered a delicacy next to the iguana. The iguana was stewed over a slow fire. An earthenware chafing dish made to fit the size of the iguana was a local development in ceramics.

Raw food was also consumed in the form of underdone or raw fish, while worms and grubs removed from rotting wood were eaten uncooked.

Native ingenuity was developed in perfecting accessories for hunting and fishing. Fish corrals of closely driven piling were set in lagoons and shallow coves and new fishing gear was developed distinct from that of the river tribes of the South American tropical lowlands. Fishhooks of clamshells carved much in the form of aboriginal shell fishhooks from California were uncovered by the Museum expedition while excavating a kitchen midden at Boca del Infierno, one of the caves on the south shore of Samana Bay. When fishing, uninhabited coasts were visited, as were also the small islands off the mainland of Haiti. Large drawnets of finely woven cotton are known from the island, but the use of fish poisons was undeveloped. The presence of net weights, notched bilaterally but otherwise unworked are to be noted at all village sites not too far removed from the coast. These sinkers vary greatly in size and occur in quantity.

Other examples of native inventiveness peculiar to the food-getting habits of the island Arawak of Santo Domingo might be mentioned. A development in fishing technic was the use of the sucker fish (remora). The powerful sucker developed on the upper side of the head is naturally adapted by this species of fish to attach itself to other fish. This was observed by the Indians who then captured a remora alive, tied a cord to it, and then allowed it to escape until it became attached to a large fish or turtle by means of its sucker. Both fish were then drawn into the canoe, the captured fish disengaged and the remora again set free to attach itself to another fish.

Parrots were commonly held in captivity and were freely bartered; they were also offered to the Spanish as objects of trade. A peculiar development of the decoy is worthy of mention here. A native equipped with a captive parrot, a noose, and an ambush of straw or grass would climb to the branches of a tree near a thicket frequented by flocks of wild parrots. When he touched the parrot's head, it cried out and attracted another parrot. The noose was then slipped over the head of the inquisitive parrot, its neck wrung, and the bird let fall to the ground.

IMPLEMENTS AND DECORATIVE OBJECTS OF SHELL AND BONE

In southwestern Florida, picks, celts, and utensils or implements of varied description were fashioned from species of the *Busycon;* in aboriginal Haiti, varieties of the *Strombus* were similarly employed. Objects of personal adornment, amulets and pendants, fetishes or zemis, necklaces and beads, all were worked from varieties of shell of the conch, clam, and other bivalve or univalves.

The presence of conch-shell bowls, plates, or utensils and implements of any description has been characterized as pre-Arawak, and has been attributed to the "Ciboney" in Cuba. Shell heaps and kitchen middens in Santo Domingan caves and deposits in open village sites reveal great quantities of such implements. A disturbing element is the invariable juxtaposition of crude and well-fashioned shell utensils and implements in the open village sites when no evidence of culture stratification appears to the careful investigator. Another problematical factor is the relationship existing between the undoubtedly Arawak pottery and the crude stone objects occurring in the same level of the midden. It has also been observed that objects of shell or of coral occur most frequently in those kitchen middens and former Arawak village sites nearest the seacoasts where suitable stone for shaping into celts and other implements can not be obtained. It is true that many objects of aboriginal provenience found their way into native barter and so traveled a long way from the place of their manufacture, but ordinarily objects of shell were utilized when stone was not available, also when, as in sites near the coast, there was a superabundance of shell available.

It may be assumed for sake of an available hypothesis that, the cave culture of Samana Bay in eastern Santo Domingo where implements and utensils of shell predominate to the practical exclusion of manufactured objects of pottery and stone, was developed by a pre-Arawak people. The Arawak type of culture in Porto Rico and in eastern Haiti is characterized by additional, more sophisticated objects of material culture, such as axes and celts of polished stone, painted and unpainted pottery characterized by applied figurine heads and geometrical, incised decorative designs; and generally,

by a conventionalized decorative and religious art displayed on media of shell, bone, stone, earthenware, gold, and wood. On careful count and analysis, more and better-made implements, utensils, and other objects fashioned from conch and other species of shell may be recovered from any Arawak village site in Hispaniola, if situated within 20 or 30 kilometers of the coast, than can be obtained from middens within caves supposedly occupied at one time by some pre-Arawak people. Implements as well as utensils whether shaped from stone or shell are rare in the cave deposits. The middens consist practically entirely of vast quantities of shells of conch and other mollusks, that have been either roasted or boiled, shattered, or otherwise opened to extract the meat of the mollusk. In lesser quantity are to be found bones and carapaces of turtle, and the bones or scales of fish. Mammal bones are least in number. Layers of ash and of charcoal are thick where the location of a primitive hearth surrounded with stones used in connection with the preparation of food indicates the center of activities in the life of the aboriginal troglodytes.

One type of implement was found to be fairly abundant in the cave deposits of Samana, namely, small picks crudely shaped from the outer lip of the conch (*Strombus pugilis*). These picks were useful in extracting the mollusk from its shell. Although an improvised implement, it is difficult to produce, as it must be struck off with a single blow.

A much larger pick was recovered in considerable numbers from various Arawak sites near the northern coast of Santo Domingo. This type of pick was shaped from the worked rib of the West Indian manatee or sea cow (*Trichechus manatus*) and has an excavated hafting groove at its center.

Gouges and beveled celts cut from the shell of the large conch (*Strombus gigas*) are characteristic of the Arawak of Hispaniola. These implements were useful in dressing wooden stools and in rounding out canoes after they had been charred by fire. Small tubular pestles were also cut from the rib of the sea cow (the West Indian mermaid of Columbus).

Decorative art in shell is best illustrated in the form of amulets, pendants, beads, and the small carved personal totems, gods, or so-called zemis. Perforated oliva, ultimus, and bulla shells were used as beads and in necklaces. Both transverse and lengthwise perforations are common. This type of shell bead is characteristic of Arawakan culture throughout the Greater Antilles. Perforations are uniformly made with a saw or grinding tool and rarely by drilling.

Shell pendants take on various forms. Some of them are purely decorative, others are undoubtedly amuletic and are referred to as zemis, still others are just ornaments. Pierced and unpierced gorgets

of worked conch shell occur in much the same manner as found in middens in Curaçao and other islands off the Venezuelan coast. Many of these discoidal objects of worked shell are unperforated, others show a bilateral drilling. Zoomorphic figurines are cut in intaglio from the solid, cameo-fashion, like the discoidal shell gorgets of Tennessee and other southeastern States. The carved figure of the frog and of the turtle frequently occurs as an excellent example of aboriginal art in shell.

ZEMIS

Swallowing sticks of bone or shell are an adjunct to the religious ceremonialism of the Arawak of Porto Rico and of Haiti. An example of this form of religious art is the worked section of a manatee rib which has been shaped somewhat like a spoon handle with flat, plain surfaces tapered to a truncated end section but surmounted at the thick end with the carved anthropomorphic figurine of an aboriginal god.

A form of zemi common to the Greater Antilles is a zoomorphic figurine carved from the shell of a conch and fashioned without arms, while legs are represented as flexed under an erect body. A marked triangular elevation with deeply incised borders appears at the lower abdominal section. The head is devoid of representations of facial features, except for the prominent snout region, and a high protruberance at the back of the head. A deeply incised groove separates the leg sections from one another and from the triangular abdominal projection or apron. This form of zemi is representative of the archaic and is protean in design. Most of the smaller zemis, whether fashioned from shell, bone, wood, or stone, have two biconical perforations at the back of the head for suspension.

The amuletic zemis seem to have been for the most part of stone, in the form of small anthropomorphic figures. They conform in detail to the general features of the corresponding type of zemi fashioned from shell.

Aside from personally owned totemic creations of zemis, there were communal gods, the property of the village. These were kept in the house belonging to the village cacique, built a little distance from the rest of the settlement. Here, too, was an artistically carved wooden table made "like a dish" on which was the powdered tobacco later to be laid on the head of the village zemi. The carved cave stalagmites representing zemis were the center of ceremonies associated with the religious life of the village.

Not all ceremonies connected with native religion were held in caves as the following description will show. Ramon Pane describes a religious ceremony associated with agriculture and fertility rites somewhat as follows. The cacique appointed a day for the celebration and announced it through his messengers. The people assembled

decorated appropriately in paint and feathers. This applied not only to the men, as the women were also given to painting their bodies. All had their arms, and legs from the knees down, covered with ornaments of shell which rattled as they moved. The cacique entered the zemi house where the shamans were preparing the zemi and sat down on a stool at the entrance. He then began beating the extended lateral surface of a hollowed wooden drum which was as long as a man's arm and resembled a calabash with a long neck. Another form had H-shape and rectangular holes cut bilaterally through the thin wooden walls. Oviedo described such drums as making a "bad noise."

After purging themselves by vomiting produced by thrusting a swallowing stick of carved manatee rib down their throats, the villagers began a ceremonial chanting while squatting before the zemi. Women appeared carrying baskets of bread, which was first offered to the zemi and then distributed among the celebrants, who carried the portions back to their huts as a powerful amulet against hurricanes and other disasters. The singing of "arietos," epics in honor of the cacique and his ancestors, occurred both on this occasion and at other social gatherings. The musical maraca, a closed hollow reed or wooden cylinder pierced transversely with wooden rods against which pebbles were shaken in rhythm accompanied the recital of the arietos. There is no reference in the literature to the aboriginal use in Haiti of flutes and of pan's-pipes as in South America beyond the Amazon.

Not all zemis or aboriginal deities were of the sort described in the ceremony. Fewkes classifies the several forms thus: "The name was apparently applied to anything supposed to have magic power. The dead or the spirits of the dead were called by the same term. The designation applied both to the magic power of the sky, the earth, the sun, and the moon, as well as to the tutelary ancestors of clans. Zemis were represented symbolically by several objects, among which may be mentioned (1) stone or wooden images, (2) images of cotton and other fabrics inclosing bones, (3) prepared skulls, (4) masks, (5) frontal amulets, (6) pictures and decorations of the body."

CLOTHING AND WEAVING

The Indians of Haiti possessed but little clothing, although skillful weavers of cotton cloth. In the more advanced districts a distinction between women's skirts according to the rank of the wearer was made, the typical garment of this description reaching from the waist to mid-thigh. The Lucayans of the Bahamas, and the male population of the Greater Antilles generally went entirely nude. Both sexes wore ornamental bandages on upper arms, below the

knees, and at the ankle. The legs of women were swathed with cotton bandages from ankle to the knee. Similar ornamental bandages are still worn in southeastern Panama by the Chocó Indians. Presence of such cotton bandages is represented on a wooden zemi figurine now in the National Museum.

Spindle whorls of burned clay are frequently recovered from middens near former village sites throughout the island, while netting tools, awls, and needles of bone indicate the extensive use of woven cotton yarns. No adequate description of the loom used by the aborigines of Haiti is available, but Ferdinand Columbus writes that a different form of the loom was observed by the Spanish in Cuba. It is therefore possible to infer that the Haitian form was the typical South American Arawak type, while the Cuban form showed Mexican influence.

The finding of earthenware disks, grooved, and otherwise covered with incised designs of a geometrical nature has been reported from many aboriginal village sites in Haiti. The use made of such objects remains problematical. They may have been used as stamps for applying paint for bodily decoration, or they may have seen use in applying decorative designs on cloth. It is more probable that they are gaming disks. Tubular disks of earthenware decorated with carefully incised geometrical designs are more definitely identified as stamps for applying designs to pottery vessels before firing.

Hammocks, both of the netted and woven varieties constitute a striking example of textile development among a people who wore little clothing and possessed little cloth, although retaining a South American weaving technic brought with them to the island from the mainland.

USES OF STONE

Aboriginal Haitians did not use stone architecturally. There are few fixed works, other than shell heaps and large middens near the sites of their former villages. The circle of stone bowlders like that at San Juan, first described by Schomburgk, occurs elsewhere throughout the island, although its appearance is infrequent. The circle of granite stones at San Juan, each from 25 to 50 pounds in weight, are placed close together in the form of a circle, having a circumference of about one-half mile. Fewkes considered such structures as courts for use in playing ball, for ceremonial dances, and for performing rites in honor of the dead. The stone circle near Dajabon on the headwaters of the Chaquey River is similar in construction to the one at San Juan but is much smaller in its dimensions.

Minor objects of carved stone devoted to ceremonial use surpass in elaboration of design corresponding Mexican forms which are entirely lacking in South American Arawakan art. The stone collars, zemis, and stone masks are the most interesting forms of art in stone

to be noted. Stone collars are oval in shape, while Mexican analogues are mostly open and at the same time display unrelated phases of symbolic art. Haitian forms are skillfully fashioned and incorporate in their larger examples decorative panels of anthropomorphic figurines similar to rim decorations and handle lugs of earthenware vessels.

The more utilitarian objects shaped from stone are less skillfully fashioned. Decorative pestle heads are scarcely characteristic of the island, although they occur infrequently in anthropometric forms. Undecorated pestles are more common as are also the undecorated oval and oblong triturating stones which were shaped by pecking and crumbling.

The stone celt of the almond or petaloid variety occurs as a symmetrically pecked ground and polished celt throughout the entire island. Another form of polished greenstone celt with uniform, slender, oval section and straight cutting edge has an equally wide distribution in Haiti.

Monolithic stone axes are of rare occurrence, although their distribution extends throughout the Greater Antilles. They represent a translation in stone of a form of hafting employed by the island Arawak in mounting their polished petaloid stone celts with wooden-handle hafts. The tapered body of the stone celt was inserted through an opening cut through the bulbous basal section of a wooden haft. Notching or grooving for attachment of a handle haft occurs more rarely in Santo Domingo. A few double-bitted axes having notched edges and illustrating this form of hafting were recovered by the Museum expedition at Petite Saline near Monte Cristi. The grooved ax of the North American mainland is foreign to the island culture, although the lyre-shape Carib form occurs sporadically in Haiti.

Oviedo's description of the hafting of a notched double-bitted stone ax is illuminating. The haft was first cut to the required length and split from the bulbous end. The thin stone blade was then inserted in the cleft and followed with a tight sewing of liana splints encircling the haft to hold the blade and to prevent the split from advancing.

Implements of chipped stone are of rare occurrence. Absence of suitable varieties of stone, the use of bone projectile points, and the development of a grinding and crumbling technic account in part for the almost entire lack of stone chipping in the Greater Antilles. Surfaces of stone implements were generally finished by grinding, flaking being less common, although flaked implements, spalls, and cores occur in the cave middens of Samana of identical shapes as the flaked stone knives and perforators from village sites along the northern Dominican coast near Monte Cristi. As mentioned, an occasional

82322—30——33

perforating point shaped by chipping, or rechipped stone forms of other description occur in middens throughout the island. Improvised stone implements and tools, such as hammerstones, and many forms of flaked tools as perforators, drills, knives, and scrapers, are common to the island-culture complex. Polished pebbles of unknown use abound.

USES OF GOLD AND OF METAL ALLOYS

Metal was scarce in the West Indies. Gold was worked by the natives of Haiti into thin plates, which were fashioned by them into objects of personal adornment or amulets, and were frequently interwoven in belts of cotton fabric or cemented into the peculiar visor masks either as a complete covering or merely as eyes, nose, and ears. Hammering of gold between two smooth or polished stones was developed by the island Arawak as a metal-working technic after they had arrived in the Greater Antilles, as there is no gold in the Lesser Antilles except what has been introduced through the agency of primitive barter. Arawak and Carib were unacquainted with tools of metal. Neither did they understand the use of the blowpipe or of a flame for casting or fusing metal. Clay molds for casting were likewise unknown.

The metal technic of Mexico and Central America was for the most part more advanced than was that of the island Arawak, although gold leaf and sheet gold were employed in aboriginal Panama and elsewhere in the production of tubular beads and other decorative objects. Beads of solid gold like those from Florida are not found in the Antilles. Gold was apparently always worked into thin plates by the island Arawak and worn either round the neck, suspended from the nose, ears, or breast, or worked into a kind of turban or "crown" covering the head. Crescent-shaped plates were suspended from the neck after the fashion of North American Indians. In 1494 Columbus observed on the south coast of Jamaica a cacique and his wife, each bedecked with earrings of greenstone from which dangled discoidal plates of gold.

Columbus was given some metal-pointed spears on the island of Haiti, which on analysis showed gold, copper, and silver alloy. This alloy of gold and copper "guanin" or "pale gold" was reported by the Ciguayans of Samana as coming to them through barter from the island of Carib (Porto Rico). When these natives informed Columbus that pale gold and "tuob" (gold without alloy) came to them from the east they probably told the truth, as the term applied to gold elsewhere on the island of Haiti was "caona," a term they did not understand when used by the Indian guides Columbus had brought with him from the Lucayan Islands.

A spatula-shaped object of copper alloy was recovered from a midden at Anadel near Samana by the writer. It is impossible to determine its aboriginal use. It is 4 inches in length and tapers from a flattened basal section to a sharp point. The flattened discoidal basal section shows the method of shaping to have been by hammering. Similar spatulas of metal alloy and of native provenience are in the archeological collection of the United States National Museum from Bolivia, Ecuador, and elsewhere from the highlands of northwestern South America.

Lucayans informed Columbus that gold came to them from the south; Cubans said it came to them from the east; while the Parians of the Venezuelan coast claimed they obtained their gold from other tribes living on the mainland west of the Paria Peninsula. At Cumana, on the mainland, natives knew of Porto Rican and Haitian gold. It is therefore probable that aboriginal barter in gold extended throughout the Antilles from Florida to Venezuela.

Three objects of hammered thin gold plate were recovered by the writer from a midden near Monte Cristi by sieving; the objects were excavated from a depth of 18 inches. Two of the pieces are from the same midden and were found at a distance of a few feet from one another, while the third was obtained from another midden on the opposite side of the village site. Each of the three objects is of the thickness of paper and showed under the glass numerous marks or hammering and bits of gold leaf compressed into the lateral surfaces or folded back at the edges and smoothed by hammering.

Two of the objects are plain, while the third is a fragment and has fragmentary decorative designs, two of the lateral edges having been carelessly cut off, leaving only two of the original straight edges at right angles. The decorative design is crude when contrasted with the best efforts of the aboriginal potter or the worker in stone, but compares favorably with designs scratched or incised on the so-called scarified earthenware from northern Santo Domingo. Freehand curvilinear and straight line etchings, punctations, concentric circles, and dots constitute the media of design. The object is perforated and has seen secondary use as a pendant, although it is impossible from its present fragmentary nature to determine the original use. The decorative design is bilateral. This effect is obtained through alternate bilateral impressions with a blunt knife on the obverse and reverse surfaces. Thus, a series of five concentrically etched lines in the upper portion of the figure have been traced three on one lateral surface and two on the intervening spaces of the opposite surface. The soft metal is thus forced into sharply defined ridges and grooves. The same technic is carried out in shaping the remaining figures appearing in the design. Circle and dot designs representing eyes have usually three concentric circles, surrounding a central puncta-

tion; two of the circles are etched on one surface, while the third is spaced between the two but impressed from the opposite surface.

A study of the decorative designs on shell, wood, terra cotta, and other objects of aboriginal provenience from Haiti and Santo Domingo reveals many similar circle and dot, angular spur, and concentric circle designs, also terminal line etchings and punctations.

POTTERY

The making of earthenware forms in the New World is generally coincident with the cultivation of maize and cassava (yucca). Another pottery making area is the extreme northwest coast of North America where the Eskimo have developed a pottery associated in form and technic with Siberian forms. The Alaska-Siberian pottery area is characterized by a technic in which the vessel is worked from a solid mass of clay and then fired by simply placing over a fire as in use.

Throughout most of the pottery making area of North and South America, with the exception mentioned, the vessel is built up by a process of coiling. The coil method was used by the aborigines of southeastern United States and of the lowland areas of tropical South America as well.

In the West Indies, pottery was fashioned by coiling, molding being resorted to in shaping the symbolic decorative designs and the representative figurine heads which were luted onto the sides of vessels as handle lugs. Quite a large variation in surface coloring was obtained through the application of slips, mineral and vegetable (*Bixa*) paints before firing, or by afterwards washing with kaolin. The paints and slips applied before firing are fixed while the white of the kaolin is readily removed by washing the vessel in water. Many of the color distinctions are accompanied with differences in the paste, smoothness of finish, decorative design and, to a lesser degree, in form. On the basis of several combinations of these characteristics we may speak of (*a*) unpainted ware; (*b*) painted ware. The unpainted ware may again be classified as terra cotta or as black incised, while the painted ware readily falls under the classification suggested by the coloring of the inner and outer walls as red, white, salmon, maroon, and polychrome. It will be noted that this classification of the pottery of the West Indian Island Arawak is less complex than is that invented by Holmes, MacCurdy, and others in describing the ancient pottery of Panama and Central America.

It has frequently been asserted that pottery made by the Caribs was superior to that fashioned by the island Arawak with respect to firing, slips and paints, paste, and surface finish. We now have a more comprehensive knowledge of aboriginal pottery forms from Haiti and find the statement no longer adequate. If we include the polychrome fragments from Porto Rico, we must now give aboriginal

pottery from Haiti and Porto Rico a position superior to that of the Carib from the Lesser Antilles. This applies only to the painted ware which is less common than the unpainted ware.

In the aboriginal pottery from Santo Domingo and Haiti, tempering materials are uniformly of small particles of steatite, sand, and pebbles, and occasionally ashes or fragments of potsherds.

Pottery forms are less ornate and varied in detail than are corresponding forms from Central America, but are more developed than those recovered from the coast of Venezuela. Bottoms are flat or slightly concave, without support flanges, legs or rings. This characteristic at once distinguishes West Indian Arawak ceramics from Central American forms, and to a lesser extent from Carib forms in the Lesser Antilles. Then, the large globular urns or general utility vessels from tropical South American tribes are lacking, most of the Haitian forms being fairly thin walled and small in size, although the terra cotta group has a coarse paste and is frequently thick walled.

Food pots are like those from Guiana and Venezuela, oval to hemispherical, with straight or in-or-out curving margins. A characteristic type is the shallow flat-bottomed bowl with large circumference and incurved margin. Two unique forms may be seen in (*a*) the rectangular vessel with raised rim sections alternating with correspondingly depressed rim areas; and (*b*) the oblong, boat-shaped vessel with its depressed lateral margins but elevated end sectors surmounted with outward gazing figurine heads.

The unique development of West Indian ceramics is especially marked in its decorative designs. Decoration is ordinarily attained by incised lines or by applying molded figures in relief. Few of the zoomorphic figurine heads, so characteristic of the West Indian potter's art, are cut in intaglio. Another characteristic is that the figurines are freehand moldings unlike the stamped Mexican analogues. Ordinarily, the figurine head is luted onto the vessel bilaterally near its margin, but figurines characteristic of the red painted ware are incorporated in the body of the vessel. Raised surfaces constituting zoomorphic designs and forming an extension of the body of the bowl, are shaped from the same coils, with the head of the animal extending from the margin on one side of the vessel and the tail projecting on the opposite side.

The knobbed pottery belongs to the same painted red ware and apparently has a wide distribution in Porto Rico, Santo Domingo, and Jamaica. Describing pottery forms from the Cueva de Las Golondrinas, near Manati, in Porto Rico, Fewkes writes: "One of the specimens has two solid knobs on the rim; another is perforated just below similar knobs." A similar type of pottery embellishment occurs on boat-shaped funerary vessels from caves near Kingston, Jamaica. In the Jamaican forms, three buttons or knobs are in

series at the raised ends of the oblong boat-shaped vessels. Another design is in the form of a crescent-shaped ribbon of clay surrounding a central knob. This Jamaican red ware, like that from Porto Rico and Santo Domingo has very thin but well fired walls. No characteristically Arawakan molded zoomorphic figurine heads appear in this group. A double-compartment bowl of painted red ware, with a dark brown slip on its inner surface was excavated by the writer at San Juan on the north coast of Samana Peninsula, along with many other similar fragmentary or complete vessels—similar as to firing, red slip or paint, form, and decoration. The walls of this and of other well-fired vessels of the painted red ware are thinner than are those of other pottery groups, the nearest approach being the unpainted, incised black ware. The introduction of a central diaphragm separating the vessel into two oval compartments is unique. The luted ribbons of clay, placed bilaterally in vertical positions on the outer walls near the margin, place this vessel within the classification of the knobbed or incorporative decorated pottery which always comes within the painted red ware group. Similar pottery has been reported from the Cauca River valley of Colombia.

Earthenware water bottles with regularly formed necks occur in Haiti and Santo Domingo. Similar Peruvian forms are known. The specialized neck form is surmounted with a knobbed or bulbous rim. Occasionally the bulbous enlargement of the rim entirely replaces the decorative figurines which are usually luted on as decorative embellishments of the lower neck sector. This later form of water bottle, slightly resembling a double gourd, but without other decorative designs, usually belongs to the painted white ware. Occasionally the paint is merely kaolin, but ordinarily the creamy white paint is well worked into the smoothly polished surface. The white painted ware is usually further distinguished by a creamy white or gray granular paste, distinct from the black loamy clay paste characteristic of most of the earthenware from the island. In form, the water bottle is spherical, having been shaped by coiling and hand modeling, aided with a calabash fragment or conch shell spatula.

The effigy canteen from Central America is occasionally duplicated in finds from Haitian kitchen middens. This form is distinct from the usual in Haitian earthenware forms in that the facial features of the effigy or figurine head are luted on to the body of the vessel which is itself incorporated in the design as the figurine head. This form of effigy canteen occurs on the Gulf coast of Florida, also in Mississippi, Alabama, and in Louisiana.

A punctate decorative design, resembling forms from Florida and the Gulf coast, appears as a common type of decorative design on the north coast and in western parts of the island. More or less deeply incised pits are regularly excavated in series of from one to six or more

lines entirely encircling the vessel above the shoulder. This archaic design pattern appears on South American earthenware vessels from Venezuela and Colombia. Other survivals of archaic decorative design are several forms of applied eye molding so well described by Spinden from Mexico. An applied ribbon of clay resembling a coffee bean is the more common form. A mere depression, or gouged out area, also a central punctation or node surrounded with an applied ribbon of clay, are other characteristic forms of eye representation. The banded punctate embellishments appear frequently on the painted ware, principally red, or maroon, while the archaic forms of eye representation appear on unpainted ware.

A decorative panel of incised lines on the incurved shoulder ridge of earthenware vessels is a common method of applying a decorative design employed by the aboriginal Haitian potter. Both vertical and horizontal lines are incised alternately in series. The lines are regularly terminated with rounded pits made in freehand. Scarified decorative designs are frequently produced by scratching the walls of the vessel with hachure figures before firing. The lines are roughly parallel and shallow, and appear without the terminal pits. Another form of cross hachure is produced by molding the vessel on a basketry base. When the basket is removed, the reticulated imprint of the fabric remains. Cross hachure and incised linear designs terminated with pits appear as embellishments oftenest on the black incised, unpainted ware.

Characteristic media of artistic expression, then, in the decorative designs embellishing aboriginal Haitian pottery are three: First, application of paints or slips in white, salmon, red, maroon, and polychrome paints; second, application of geometric designs in incised paneling, including series of straight lines, curves, circles, open and closed spirals; third, luting on to the body of the vessel applied anthropomorphic and zoomorphic figurine heads, or the incorporation of the extended body of the vessel as a portion of the design in effigy canteens and on the incurved shoulder of painted red ware bowls. Incised paneled designs and applied relief figures are freely used in combination, the plain knobbed or zoomorphic figurine heads being mounted near the rim of the vessel, on the incurved shoulder of which appear geometric incised embellishments. The terminal pit occurs in conjunction with straight lines and incomplete circles, while the incised or applied circle appears with a centrally excavated pit or punctation in relief.

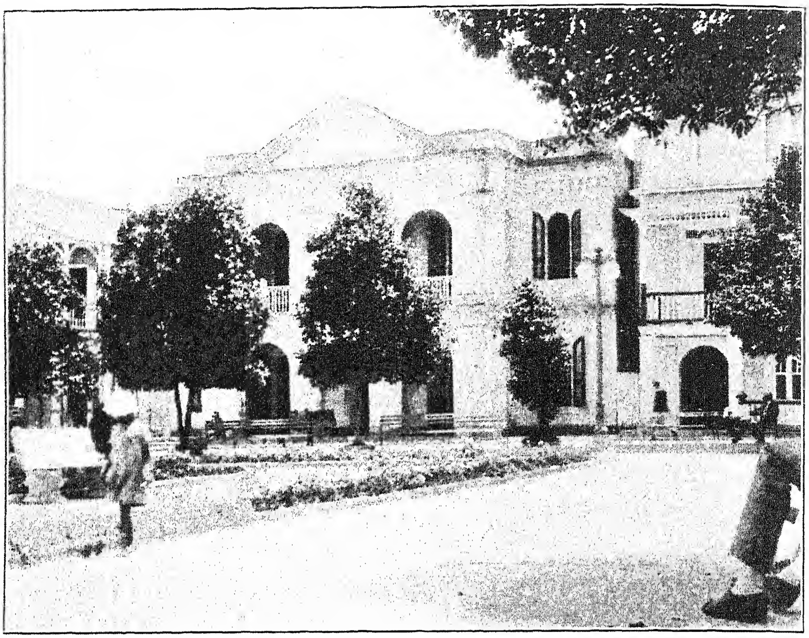
The simplicity of the freehand technic employed in shaping the molded figurine head is remarkable because of its effectiveness. Many of the clay heads are clearly intended to represent frogs, snakes, turtles, iguanas, or lizards; birds such as the parrot, owl, pelican, and others; and mammals as the jutia and sea cow. Others

are more conventionalized representations of the so-called monkey type. In this type, the upper and lower parts are molded to stand out in relief while the central portion is depressed. Horizontally incised lines of different lengths are cut transversely and are terminated with the characteristic shallow punctation.

Some of the anthropomorphic figurines are plainly caricatures, a few appear to be portrait models in clay. Headdress forms are particularly striking. The turban, as on the archaic figurines from Mexico, and other forms of headdresses and hair coiffures, are characteristic.

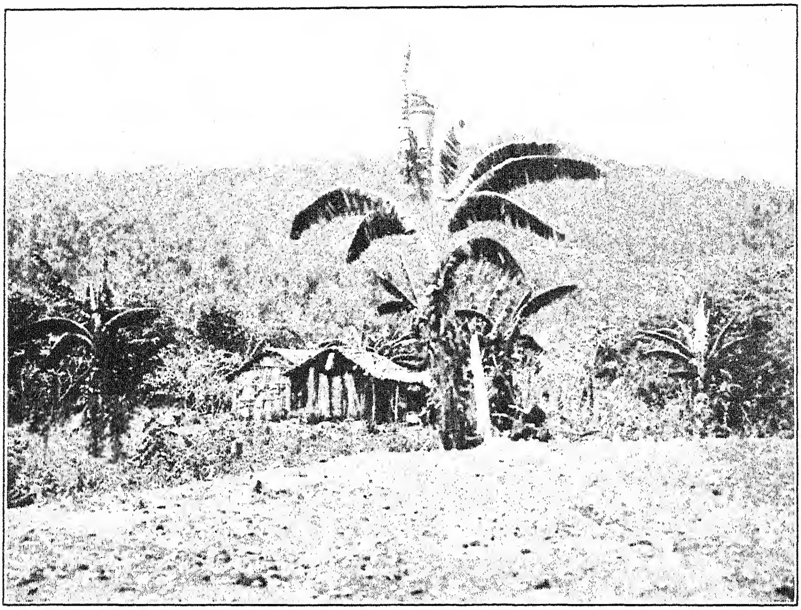
Generally it is impossible to recognize the species of zoomorphic figurine modeled in clay, because of the conventional distortions and omissions. Undoubtedly, some of the figurine heads are intended to represent zemis belonging to an individual or family. Conventionalized presentations bespeak an old and deeply rooted culture, not necessarily a high culture, but one thriving throughout a long period of time in comparative isolation. It is possible that the personages or creatures represented are in part ceremonial and belong to the social and religious life of the tribe, not necessarily bearing any definite relationship to animal forms.

CHARLEVOIX'S MAP OF THE ABORIGINAL PROVINCES OF HAITI AND SANTO DOMINGO, PUBLISHED IN 1730



1. THE "GOBIERNO" OR GOVERNMENT BUILDING AT PUERTO PLATA FACING THE PLAZA

2. ON THE MONTE LLANO SUGAR ESTATE, PUERTO PLATA

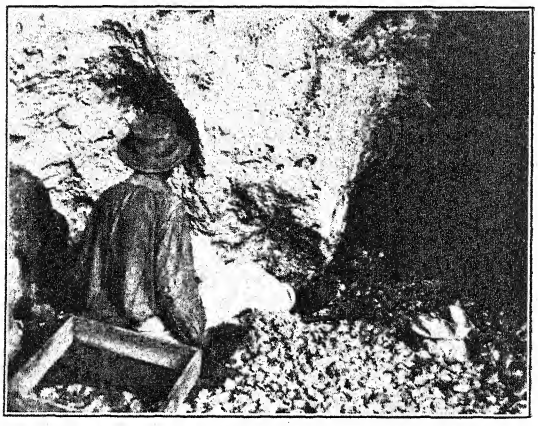


1. THE MOUND IN THE FOREGROUND IS THE VILLAGE SITE AT SAN JUAN IN SAMANA PROVINCE AFTER EXCAVATION

The thatched houses shown are typical of Samana. Walls are not surfaced with clay as elsewhere in Santo Domingo.

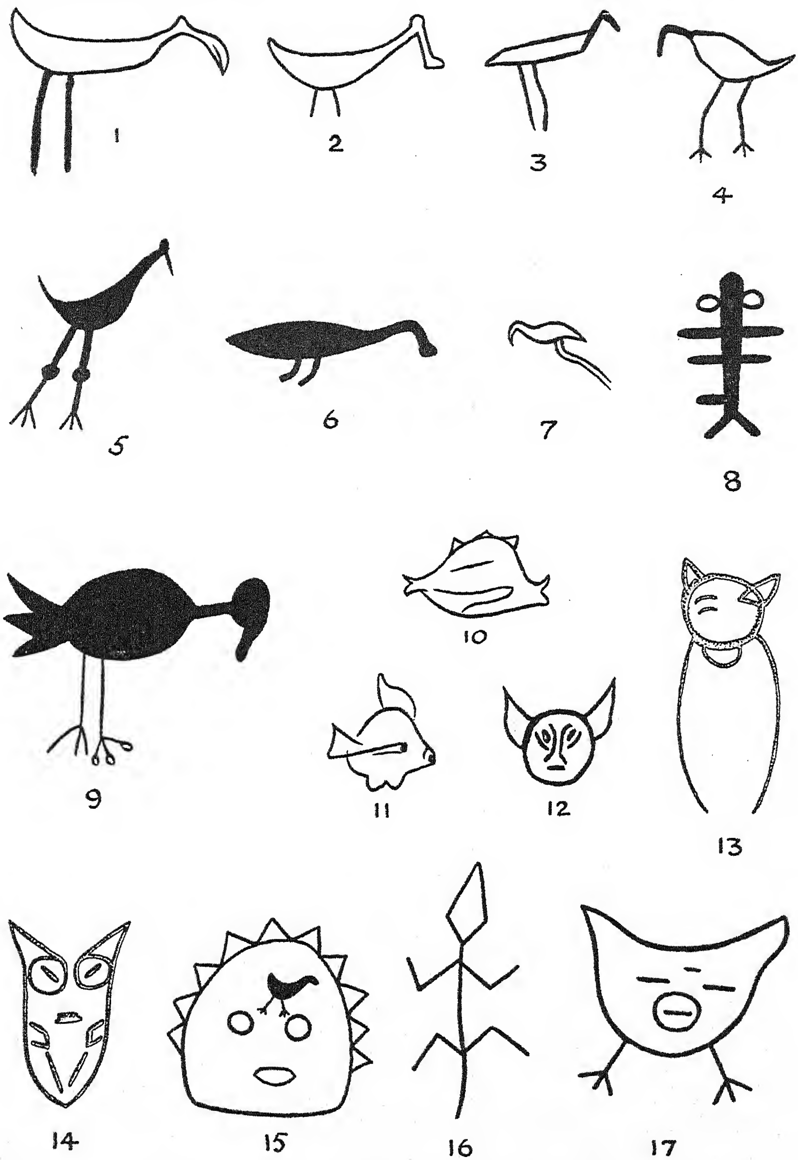
2. AT WORK EXCAVATING THE SAN JUAN SITE, SAMANA PROVINCE

1



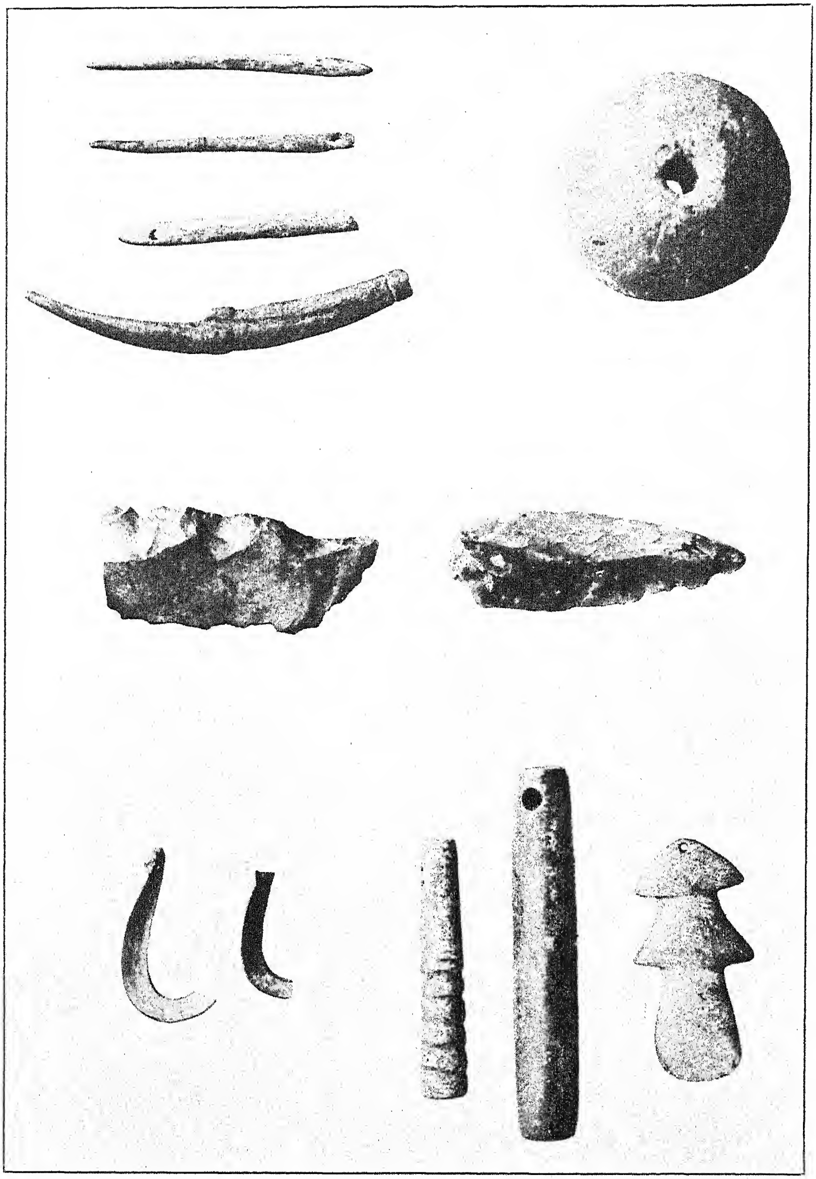
2

1. A SHELL MOUND AND KITCHEN MIDDEN AT SAN JUAN, SAMANA PROVINCE
2. LARGE HEAPS OF CORAL SHELLS (STROMBUS PUGILIS) WERE LEFT ON THE FLOOR OF CAVES ON THE SOUTH SHORE OF SAMANA BAY. SAN GABRIEL CAVE IN SAMANA PROVINCE



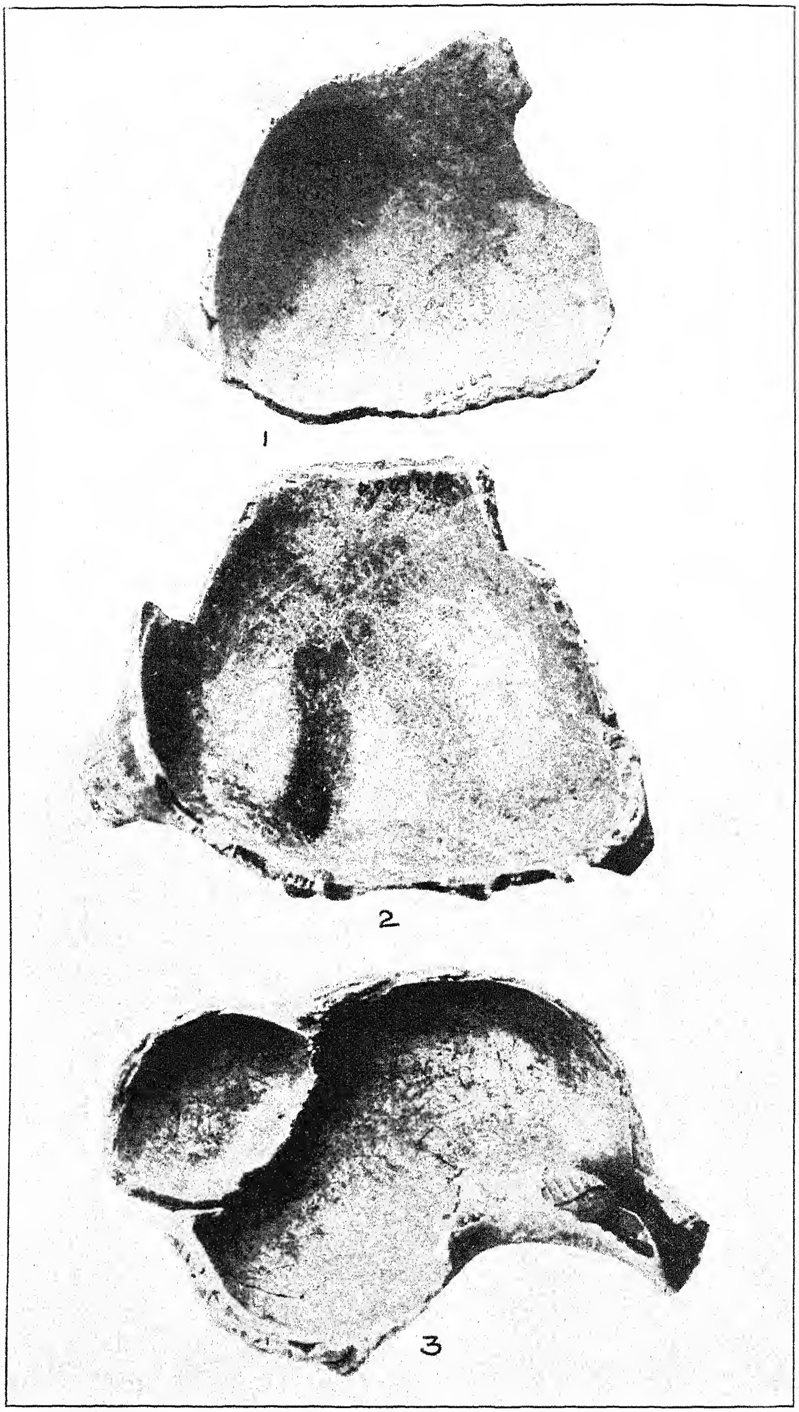
PAINTINGS OF BIRDS, FISH, A LIZARD, AND OTHER ANIMAL LIFE ON WALLS OF "CUÉVA DEL TEMPLO," SOUTH SHORE OF SAMANA BAY, SAMANA PROVINCE

PAINTED HUMAN FIGURINES AND SYMBOLIC DESIGNS ON THE WALLS OF THE "CUÉVA DEL TEMPLO," A CAVE ON THE SOUTH SHORE OF SAMANA BAY, PROVINCE OF SAMANA

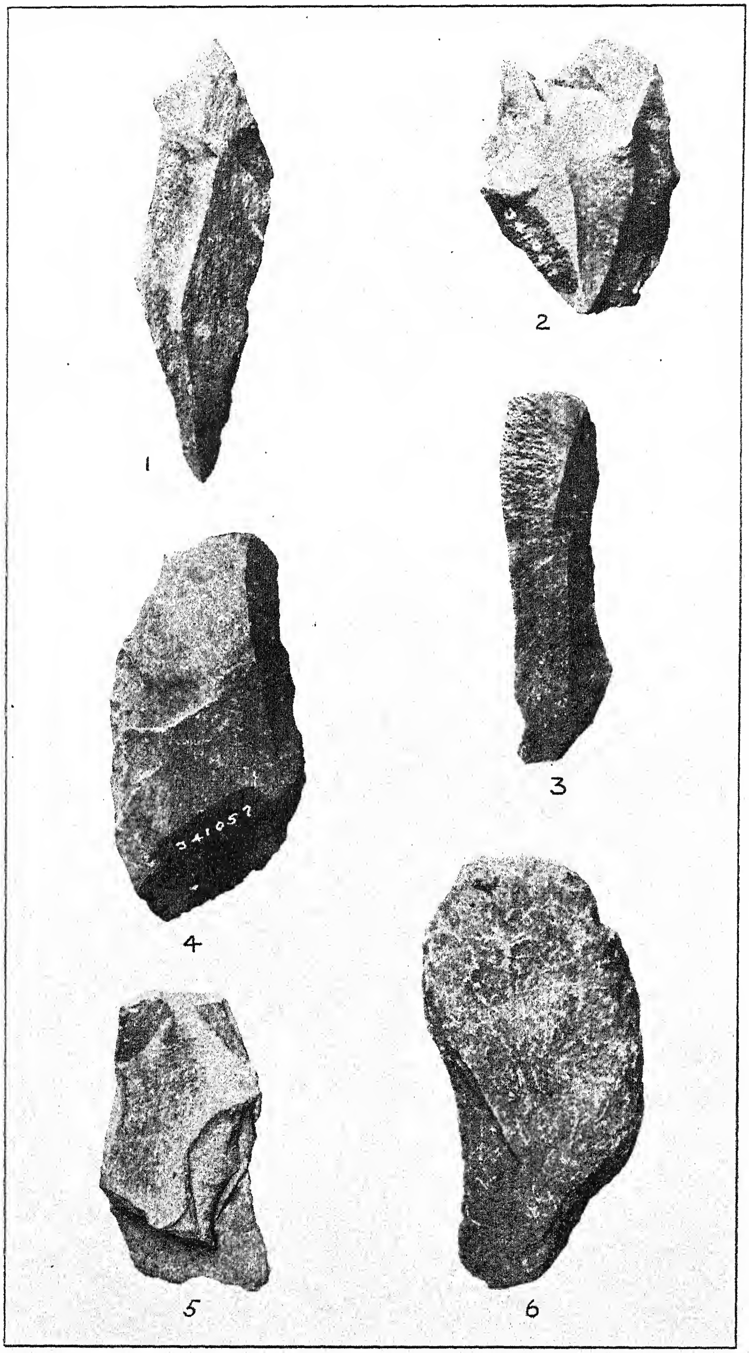


MISCELLANEOUS OBJECTS

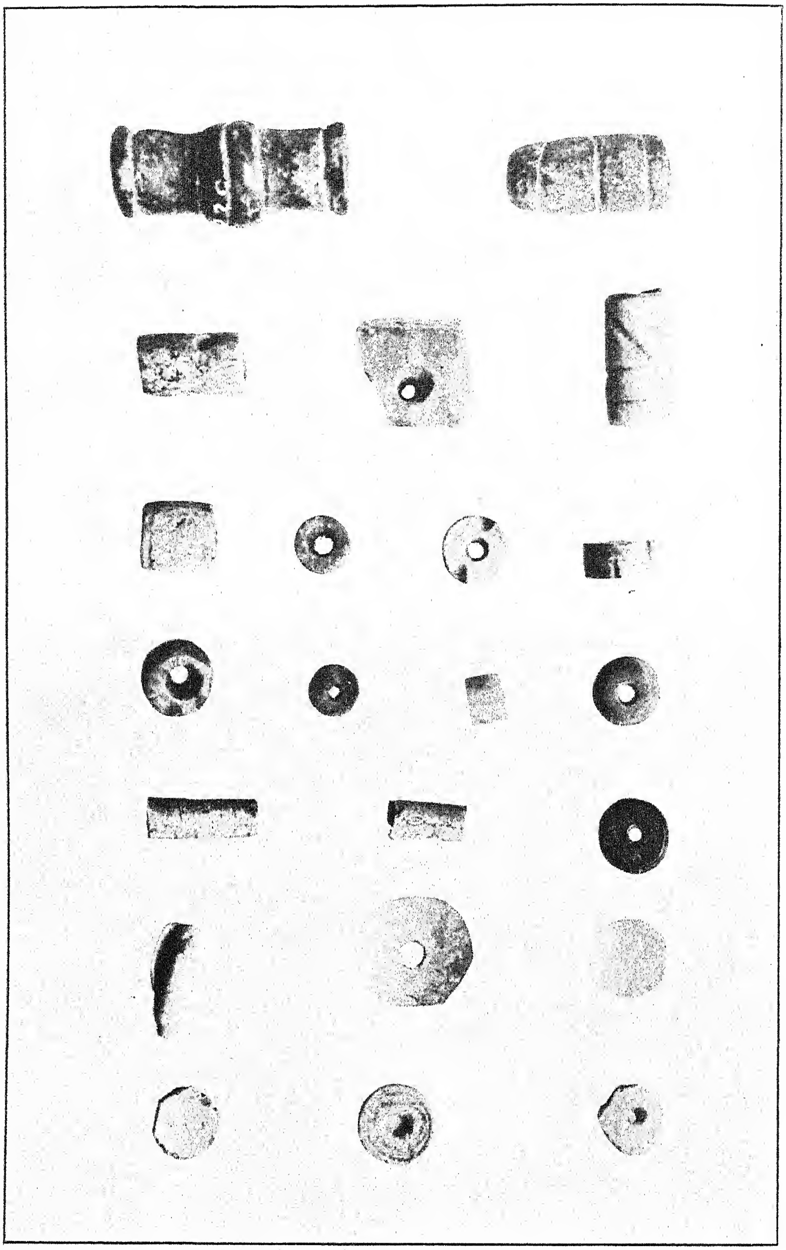
Perforated bone needles and a bodkin, on upper left; an earthenware spindle whorl, upper right; chipped stone objects, at center; two fishhooks of shell with points broken, on lower left; tubular and celt-shape stone pendants, on lower right. Monte Christi Province.



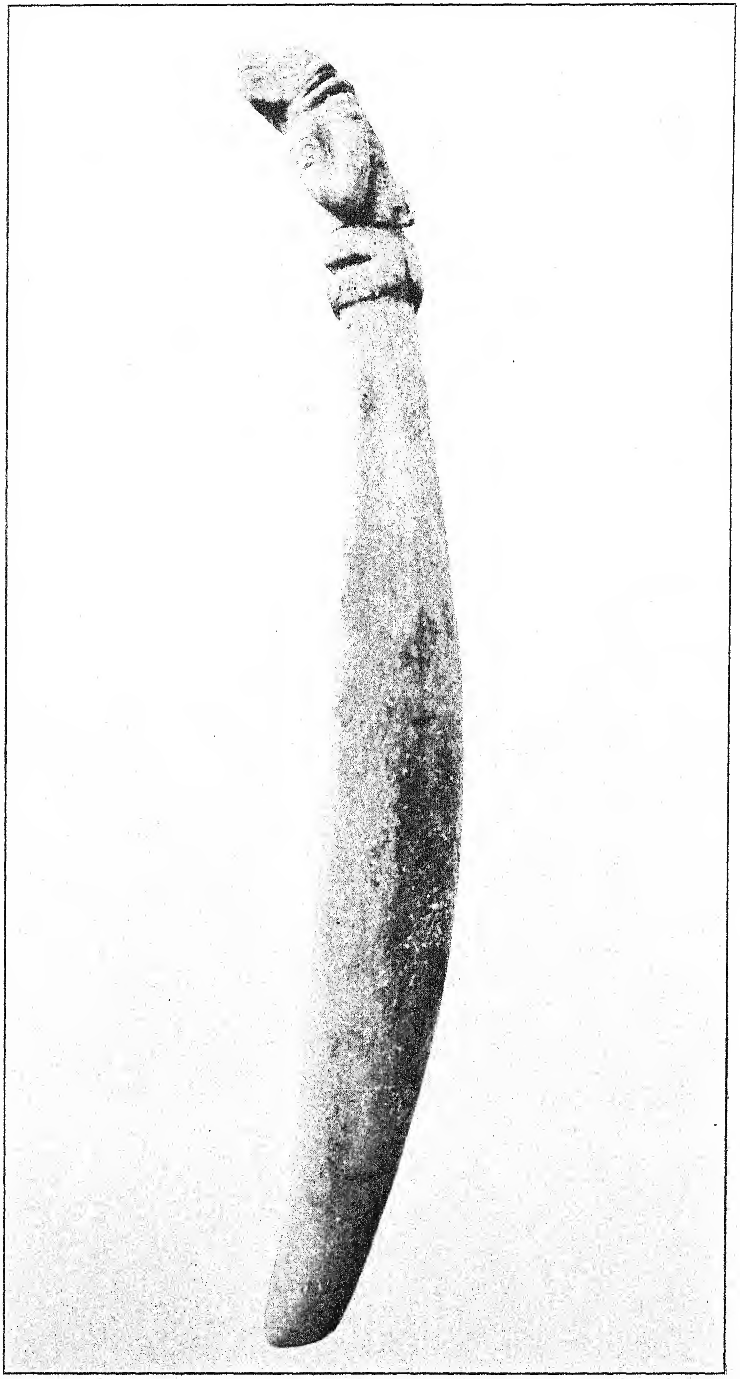
FRAGMENTS OF LARGE MOLLUSK SHELLS, PERHAPS USED AS PLATES OR OTHERWISE IN THE DOMESTIC LIFE OF THE ABORIGINAL INHABITANTS OF THE SAMANA CAVES. SAMANA PROVINCE



FLAKED OBJECTS OF CHERT AND GREENSTONE USED AS KNIVES, PERFORATORS, SAWS, ETC., BY THE ABORIGINAL CAVE DWELLERS OF SAMANA PROVINCE

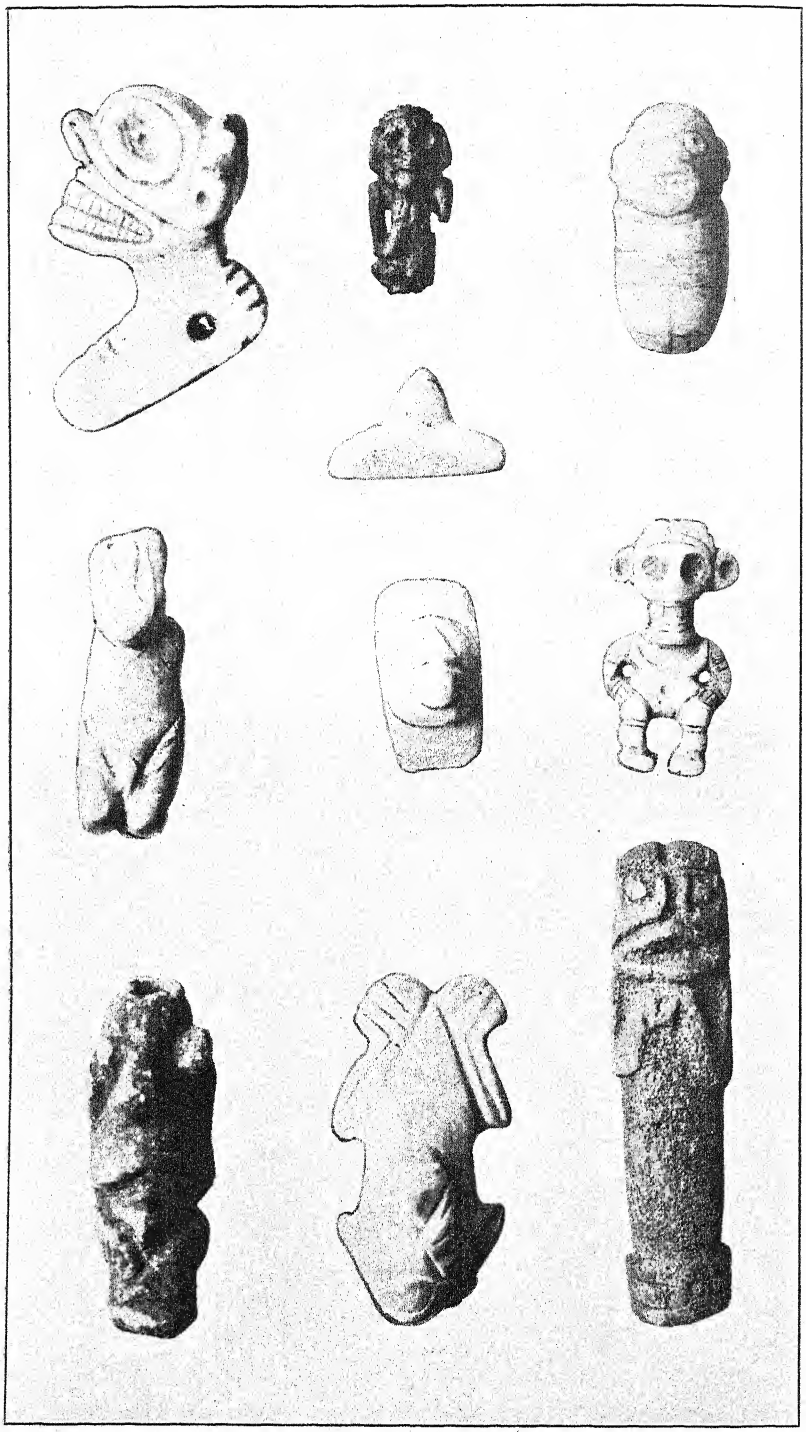


TUBULAR AND DISCOIDAL BEADS OF JADEITE, CALCITE, AND MARBLE; ALSO OF BIRD LEG BONE AND OF MOLLUSK SHELL, PRINCIPALLY CONCH. SAMANA, MONTE CRISTI, AND OTHER PROVINCES

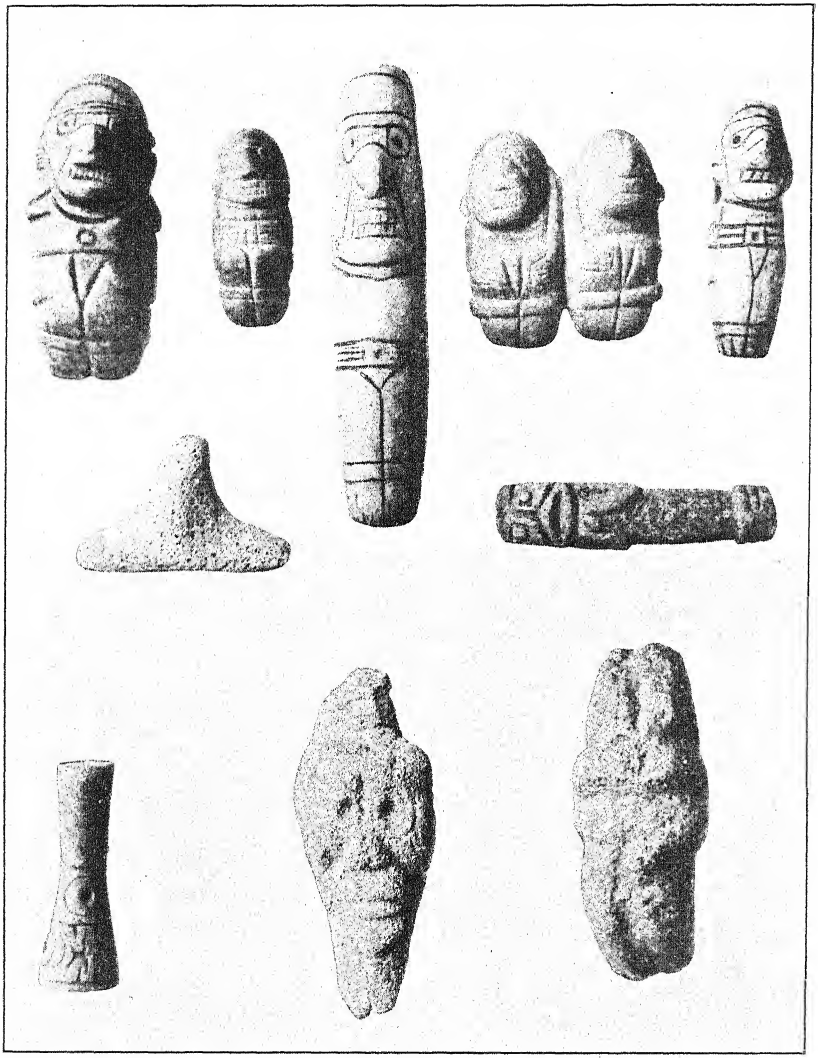


A SWALLOWING STICK FASHIONED FROM A RIB OF THE MANATEE

This object was inserted in the throat to produce vomiting preparatory to purification rites associated with Taino religion.



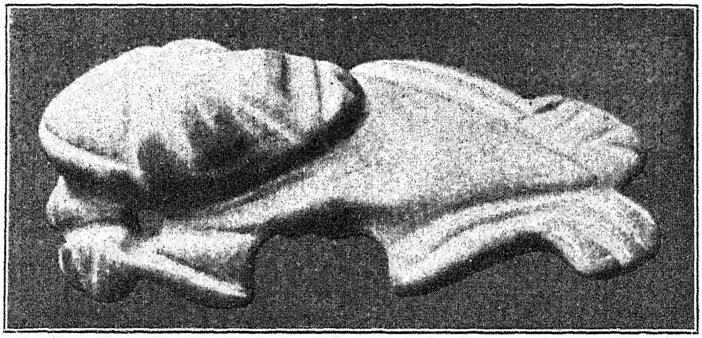
ZEMIS CARVED FROM STONE, SHELL, WOOD, AND BONE. FROM VARIOUS PARTS OF SANTO DOMINGO



ZEMIS OR AMULETS CARVED FROM STONE AND BONE

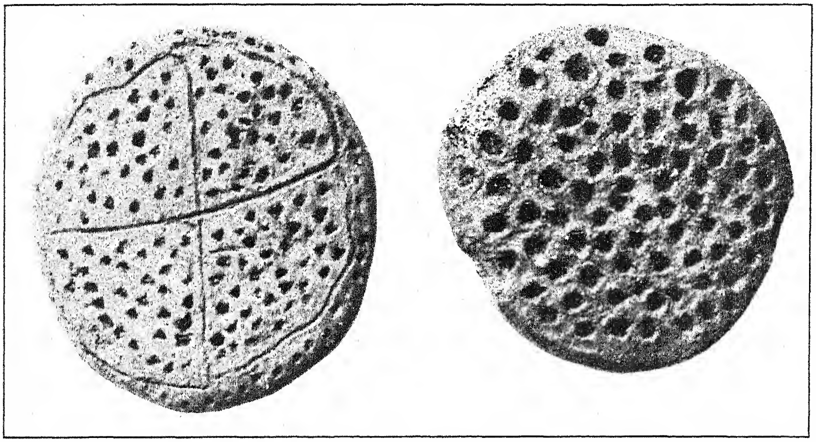
The pestle-shaped object at the lower left is from the rib of a manatee. All from the northern portion of Santo Domingo.

1

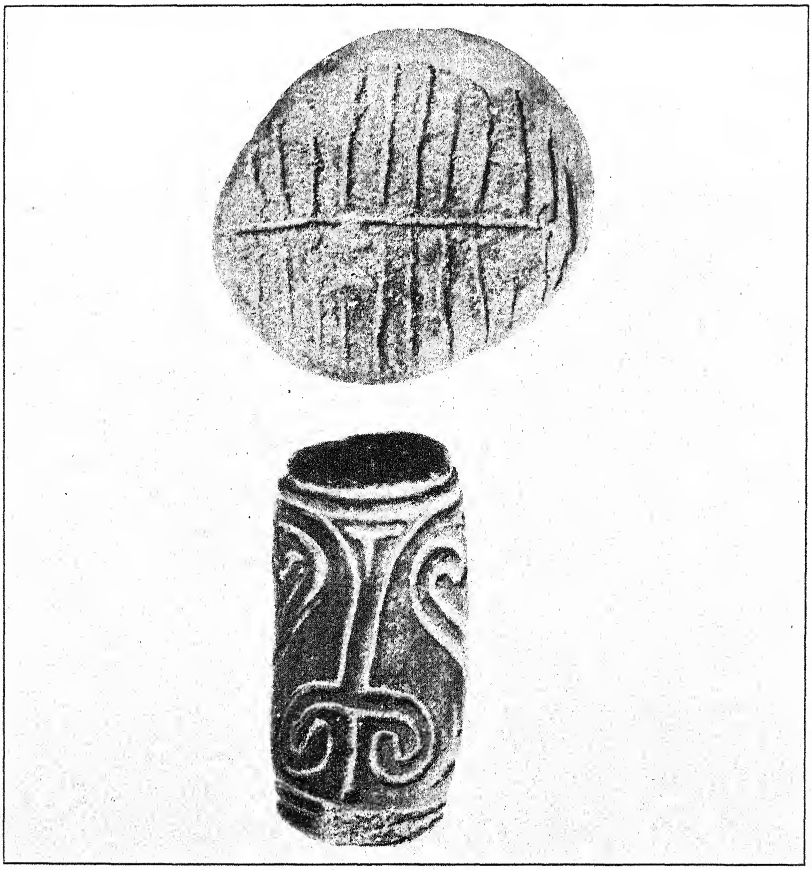


2

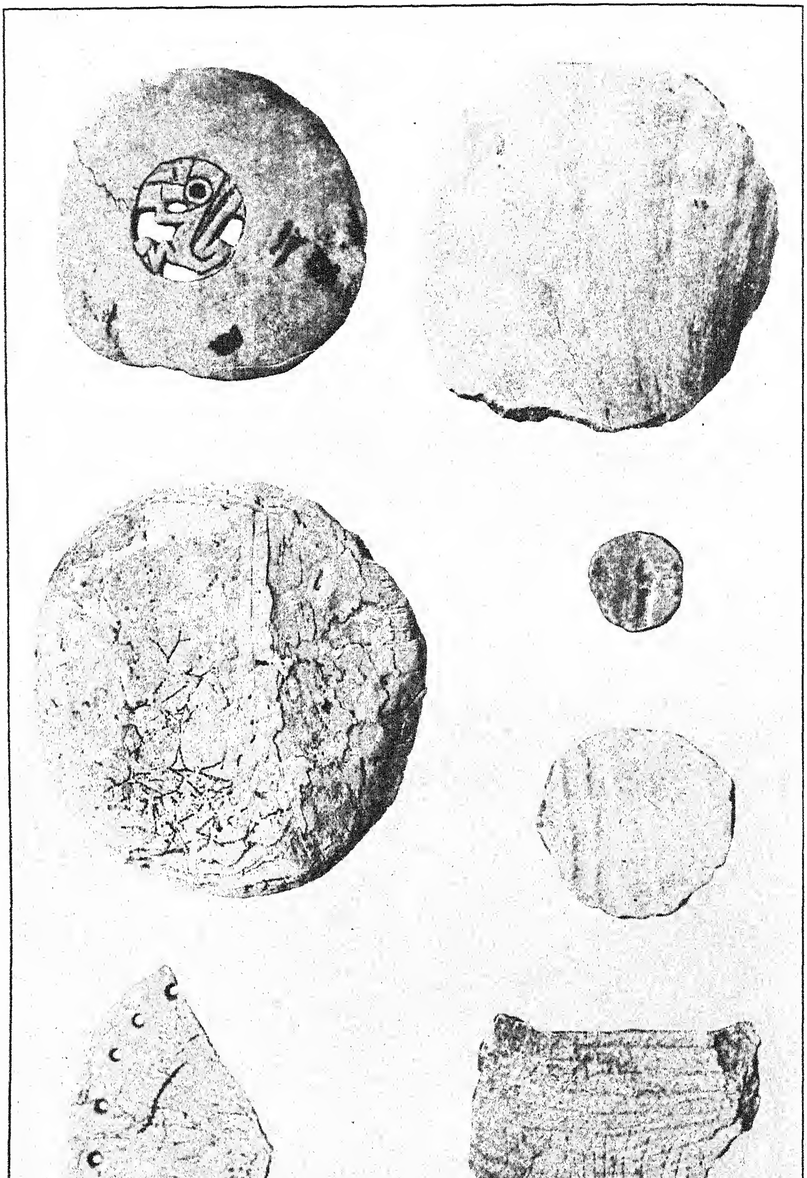
1. THIS SMALL ZEMI WAS RECOVERED FROM A MIDDEN AT ANADEL, IN SAMANA PROVINCE. IT IS CARVED FROM WOOD
2. A ZEMI REMARKABLE FOR ITS FORM. WHEN RECUMBENT IT RESEMBLES THE FROG; UPRIGHT, IT BECOMES A HUMAN EFFIGY. FASHIONED FROM SHELL. SAMANA PROVINCE



1. DISCOIDAL EARTHENWARE FORMS USED PERHAPS AS STAMPS OR IN GAMING. SAMANA PROVINCE

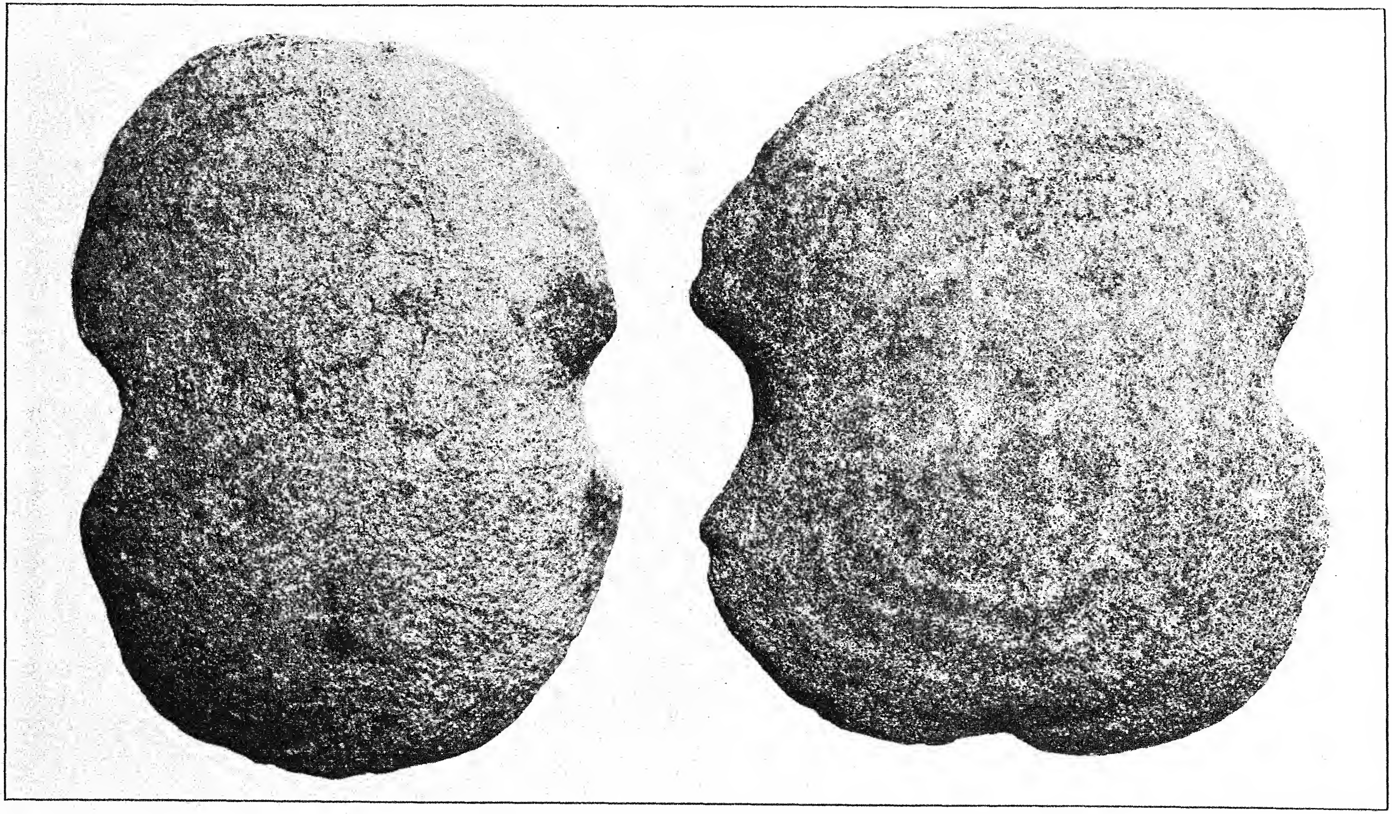


2. DISCOIDAL AND TUBULAR EARTHENWARE OBJECTS OF INDETERMINATE USE. MONTE CRISTI PROVINCE



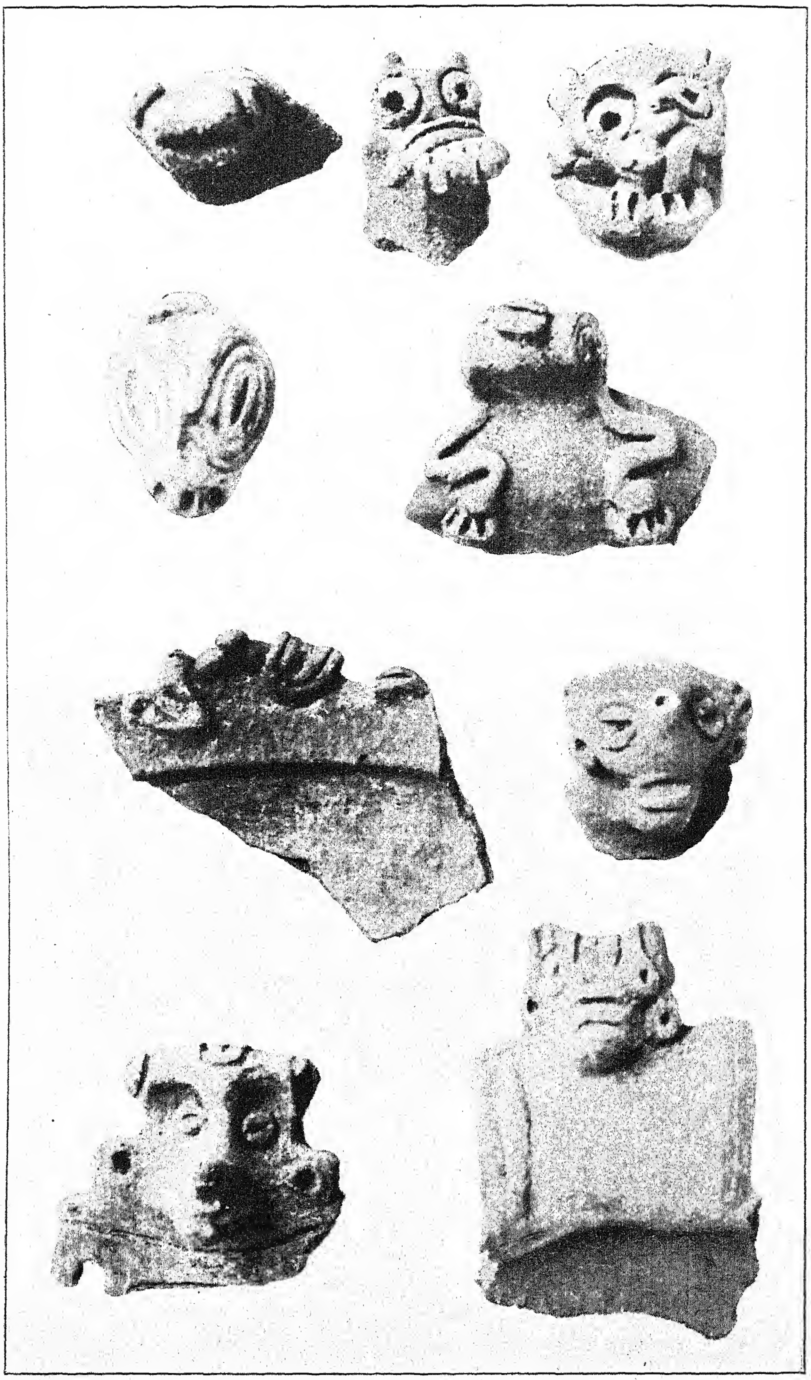
PERFORATE AND IMPERFORATE SHELL GORGETS AND DISCOIDAL OBJECTS OF SHELL

The figurine cut from the shell disk at upper left is probably that of a monkey. Monte Christi Province.



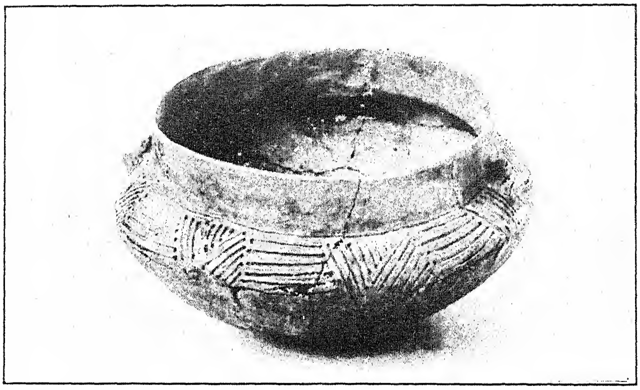
TYPES OF GROOVED STONE AXES FROM MONTE CRISTI PROVINCE

Notice the meandered etched lines decorating the ax on the right. Stone axes grooved in this fashion are characteristic of the Carib of the Lesser Antilles rather than of the Arawak of Santo Domingo.

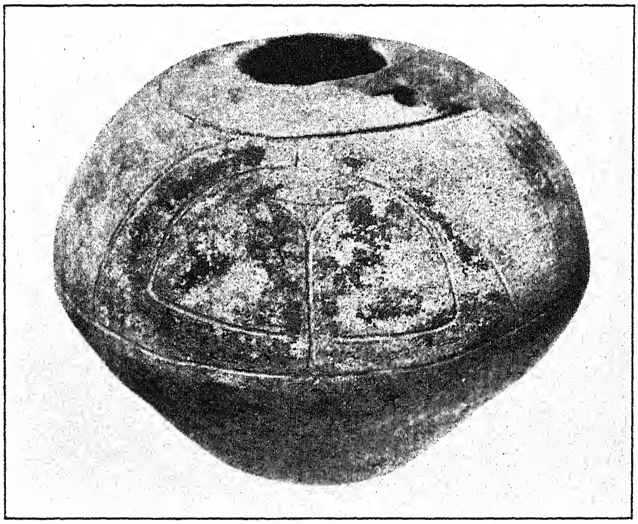


TYPES OF ANIMAL REPRESENTATIONS ON RIMS AND HANDLE LUGS OF EARTHENWARE VESSELS

Some of these appear as distortions due to the limitations of space and to the conventional modeling of the figurines.

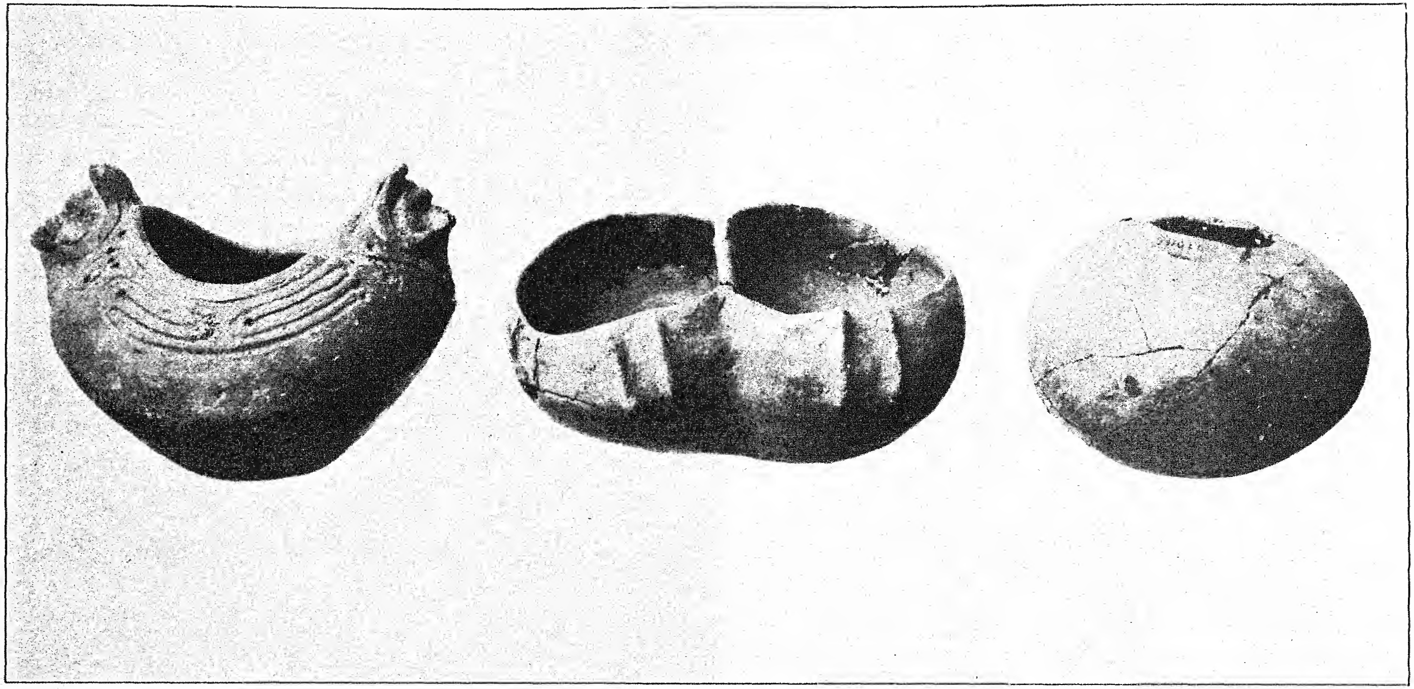


1

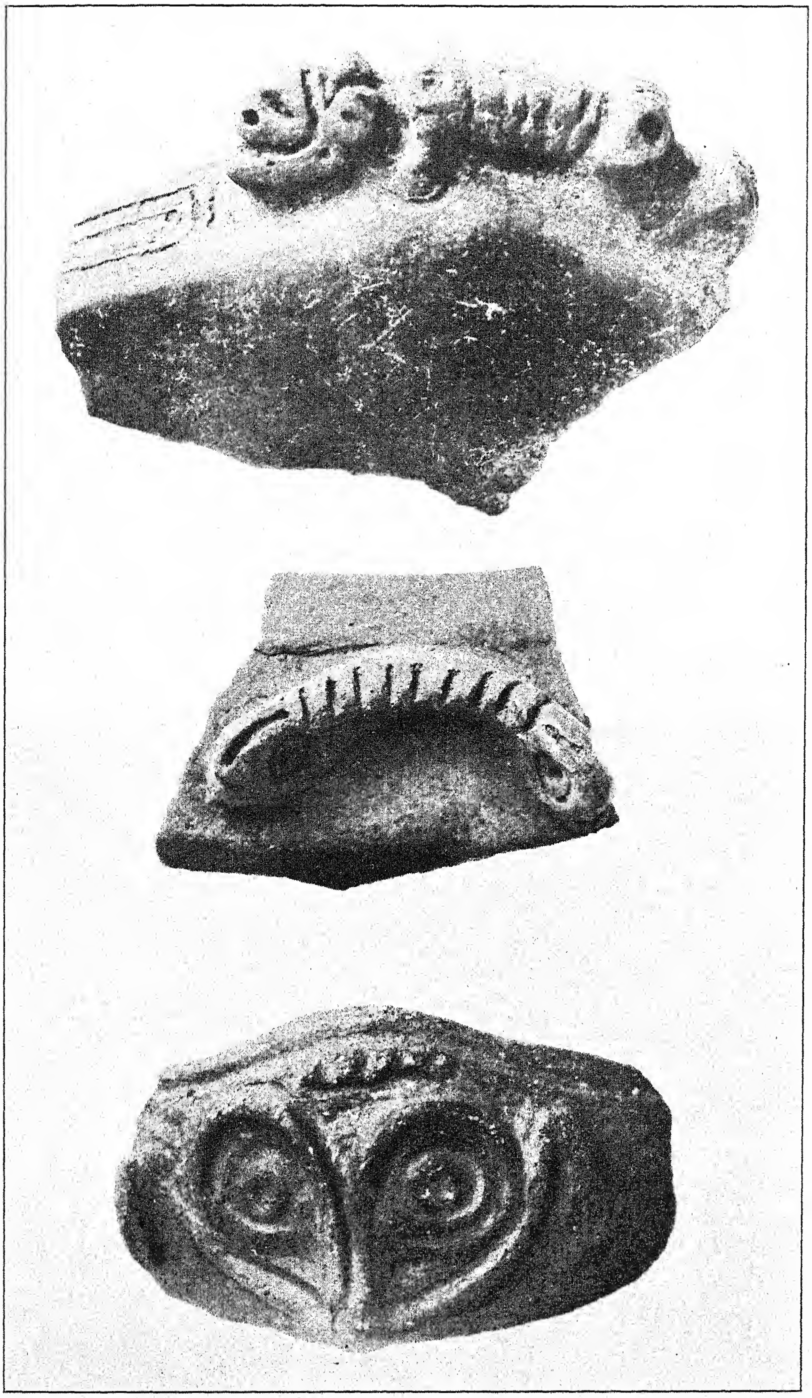


2

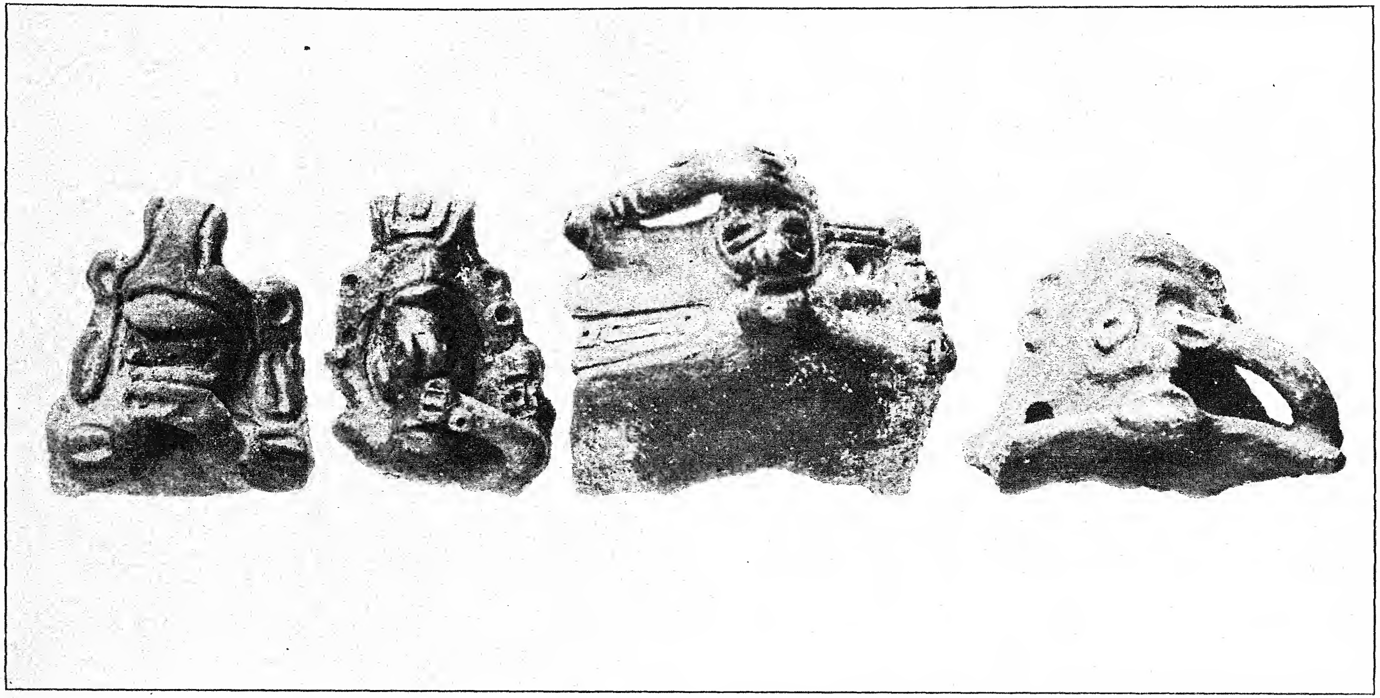
1. THIS TYPE OF EARTHENWARE VESSEL WITH ITS DECORATIVE PANEL OF INCISED LINES TERMINATING IN SHALLOW PITS RELIEVED WITH TWO OPPOSITELY PLACED MODELED CLAY EFFIGY HEADS IS CHARACTERISTIC OF TAINO POTTERY. SAMANA PROVINCE
2. THE USE OF PAINT ON TAINO VESSELS IS RARE. THIS VASE PLAINLY SHOWS PATCHES OF RED PAINT. OTHER COLORS FOUND ONLY INFREQUENTLY ARE WHITE, SALMON, MAROON, AND, RARELY, POLYCHROME. SANTIAGO PROVINCE



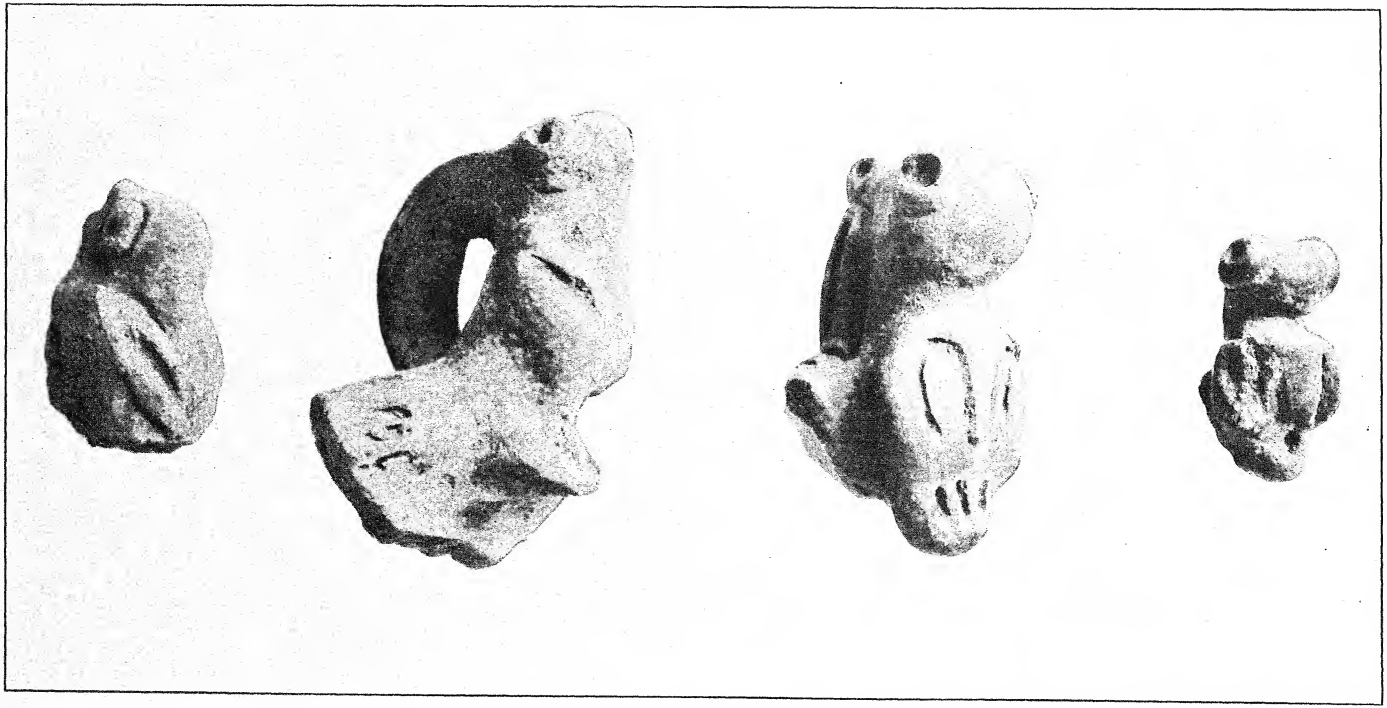
THREE TYPES OF EARTHENWARE VESSELS FROM THE SAME LEVEL OF THE SAN JUAN MIDDEN. SAMANA PROVINCE



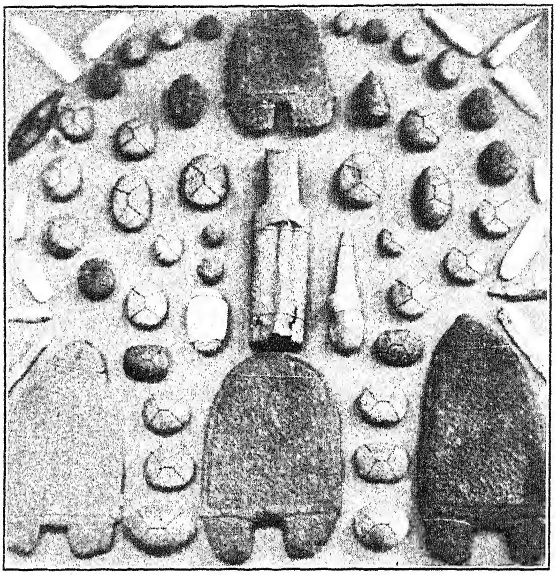
AN IGUANA, A DOUBLE-HEADED SNAKE, AND AN OWL FIGURINE AS APPLIED DECORATIVE EMBELLISHMENTS ON EARTHENWARE VESSELS. MONTE CRISTI PROVINCE



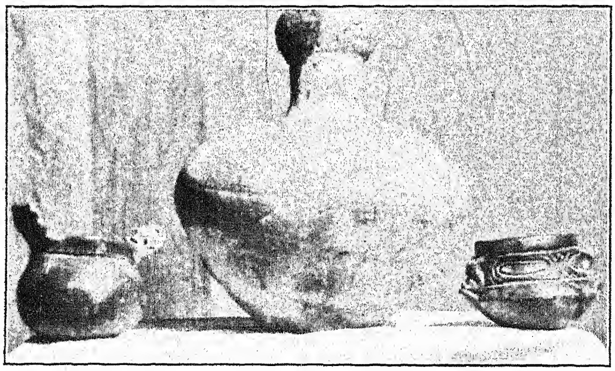
CARICATURES IN EARTHENWARE EFFIGY HEADS. MONTE CRISTI PROVINCE



MODELED BIRD FORMS. FRAGMENTS OF POTTERY FROM MONTE CRISTI PROVINCE

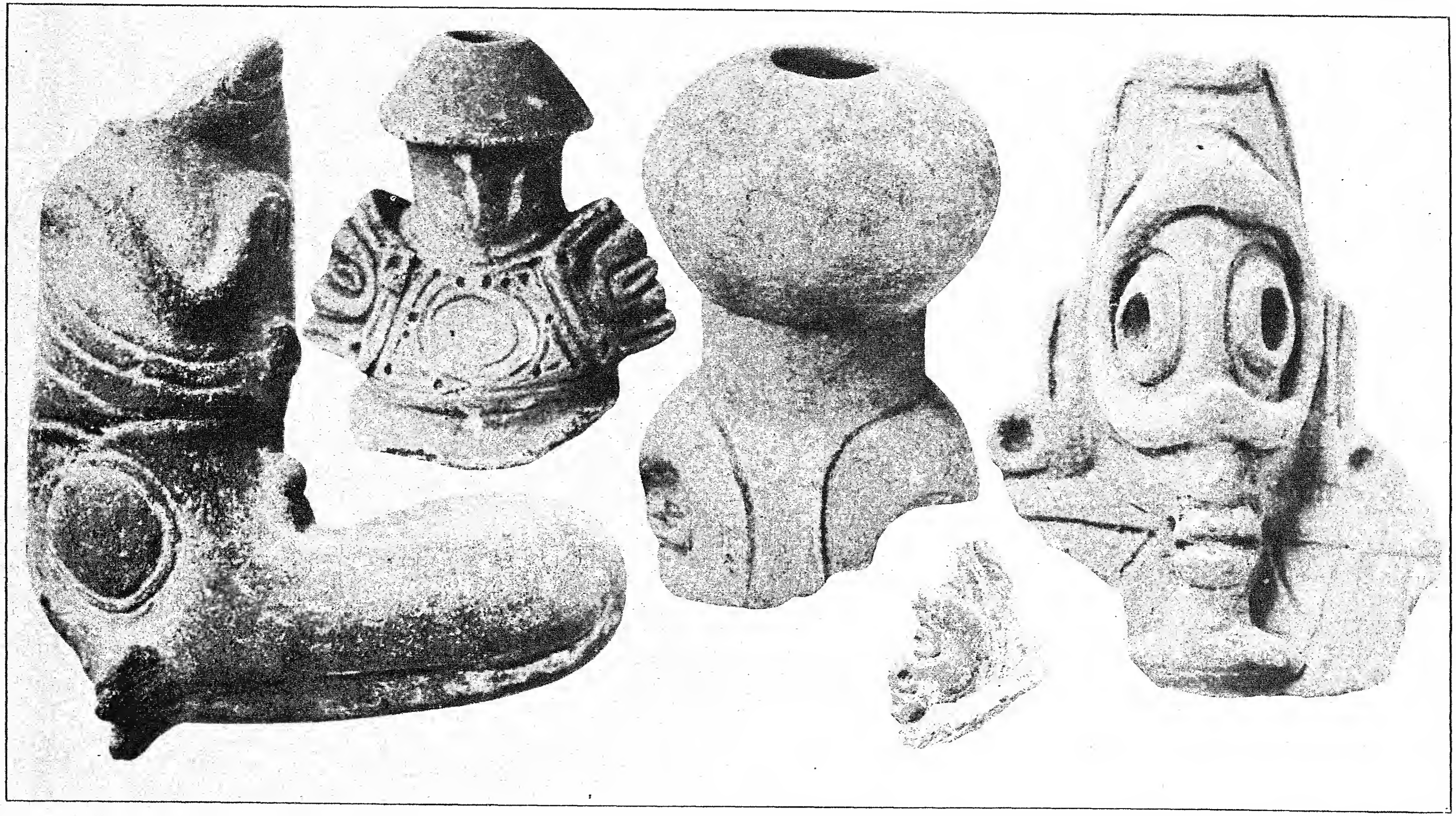


1

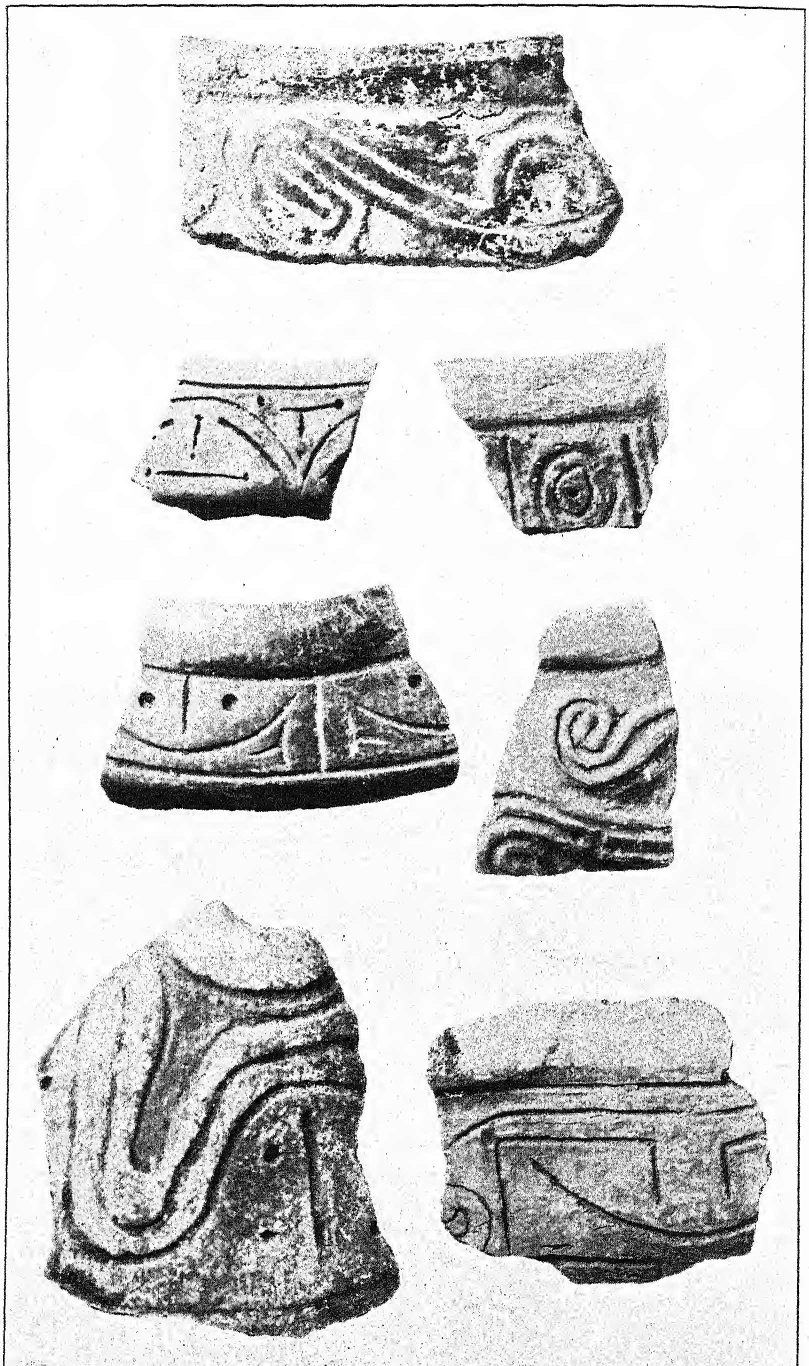


2

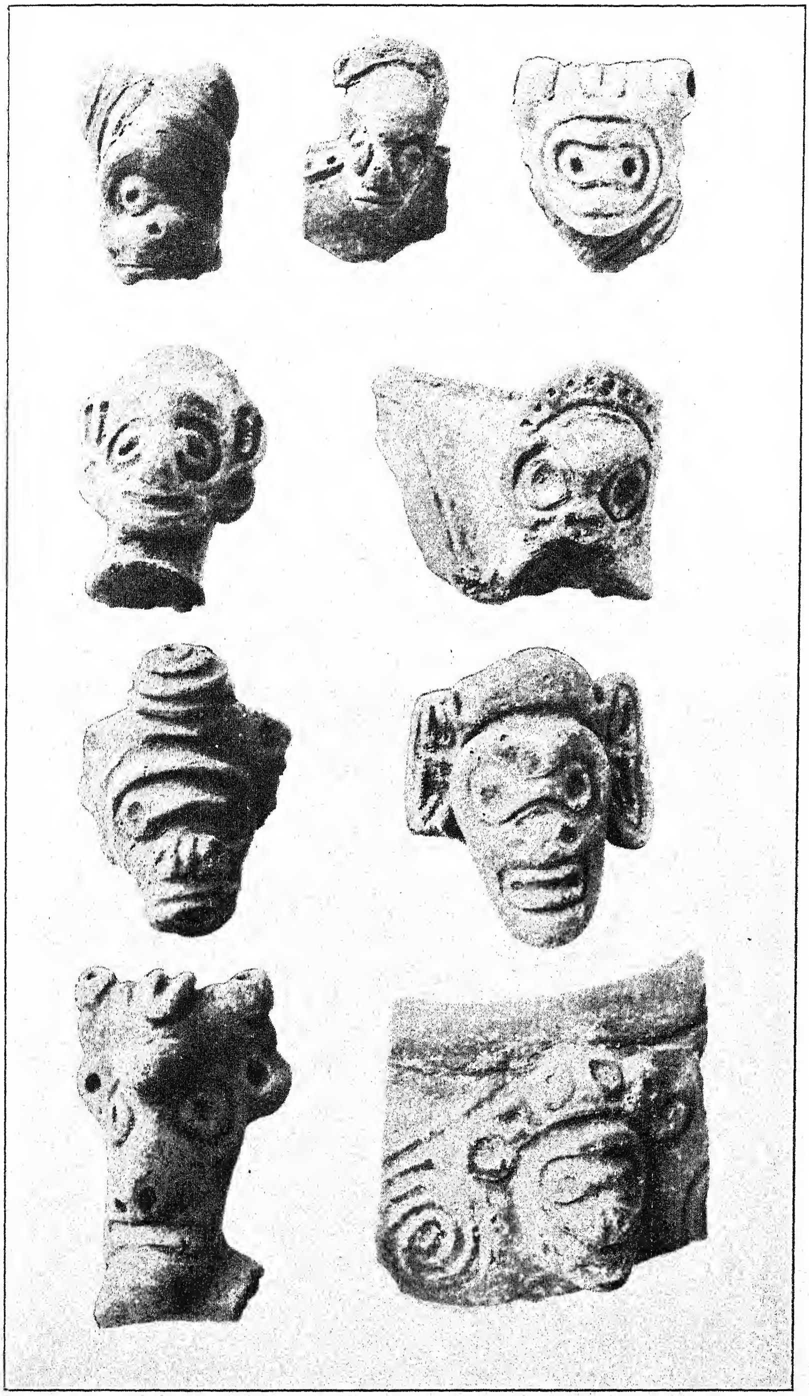
1. COLLECTION OF ANDRES SOCIAS, OBTAINED FROM VILLAGE SITES EAST OF THE RIO YAQUE DEL NORTE IN MONTE CRISTI PROVINCE. THE LARGE OBLONG STONE OBJECTS ARE CASSAVA GRATERS WHILE MOST OF THE SMALL, OVAL, FLAT STONES ARE MANOS
2. TYPES OF EARTHENWARE VESSELS FROM MONTE CRISTI PROVINCE. THE LARGE WATER BOTTLE IN CENTER IS GRAY WARE AND HAS A WHITE KAOLIN SLIP



POTTERY FORMS SHOWING REALISTIC MODELING OF THE HUMAN BODY, ALSO CONVENTIONAL DESIGNS. MONTE CRISTI PROVINCE



FORMS OF INCISED AND RELIEVED DECORATIVE DESIGN ON EARTHENWARE VESSELS. MONTE CRISTI PROVINCE



TYPES OF MODELED HEADDRESSES ON CLAY FIGURINE HEADS. MONTE CRISTI PROVINCE

THE BEGINNING OF THE MECHANICAL TRANSPORT ERA IN AMERICA

By Carl W. Mitman

Curator, Divisions of Mineral and Mechanical Technology, United States National Museum

[With 24 plates]

I. HOW MAN CAME TO KNOW STEAM

Many centuries before the word steam was ever used, learned Egyptians knew that heat, whether from the sun or a man-made fire, could produce motion of fluids or vapors contained in closed vessels. Before the Israelites escaped from Egypt there was at least one Egyptian statue of a god, that of Memnon, which on sunny days, so report says, uttered sounds like the notes of a harp. This mystified the worshipers and drew members from other sects until the priests of a rival belief succeeded in exposing the trick. Extending vertically from a water filled cavity within the statue was a small pipe with a tiny opening at the top near the mouth, fashioned like an organ pipe. When the sun shone it heated the water and the resulting movement of air up the pipe and out of the mouth produced the sounds heard. The speaking god was a mere hot-air calliope.

The science of those times was in the hands of the priests but as the secret of their grip over the people lay in mystery, they were careful to keep their discoveries to themselves. Consequently, if they knew anything about steam we have no record of it. Alexander's conquest of Egypt, however, brought in a new attitude toward knowledge. Her kings became patrons of the arts and sciences; the court of Alexandria became a school of philosophy where the learned of many countries gathered. In the hope of obtaining royal favor the philosophers put their knowledge into books. It is in the publications of one of them, Hero by name, that the oldest printed record of man's knowledge of steam is found. Hero, who lived sometime between 150 B. C. and 50 A. D., wrote a volume on pneumatics in which for the first time he discussed the several properties of steam and described a number of mechanical contrivances, some

of his own invention and others probably of Roman origin, which made use of its power. The best known of these mechanisms is a form of steam turbine called "aeolipile," but the book describes also how steam was used to open and close temple doors, transfer liquids from one vessel to another, and support hollow balls in mid-air on a column of steam. None of these devices had any practical use. They were the toy of the philosopher and the tool of the mystic, each of whom considered that it lessened his dignity to explain,

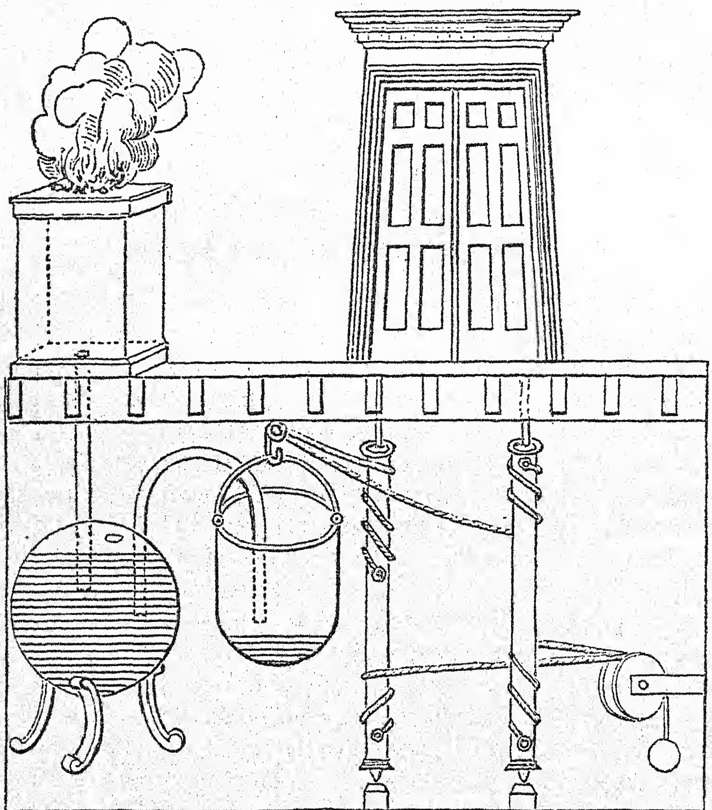


FIGURE 1.—Opening temple doors 100 B. C. Fire on the altar heats and expands the air beneath and drives water into the bucket. The bucket descends, turns the columns and opens the doors. When the fire goes out, the air is condensed and the water is syphoned back to the sphere. The counterbalance then falls and closes the doors

let alone suggest, practical uses to the masses. Nothing, therefore, came of their findings.

Shortly after Hero's time Alexandria fell into Roman hands and a court of victorious soldiers replaced the court of the philosophers. Science fell into disrepute in its most powerful stronghold. Fourteen centuries passed before men again turned in large numbers to the study of the world of nature. During all this time there appears to have been nothing written on steam.

On the revival of learning in Europe at least five Italian philosophers translated Hero's book, but with one exception they were indifferent to practical mechanics. Baptista Porta, a mathematician of Naples, in his translation and commentary, however, did suggest, by drawings and descriptions, apparatus for using steam to raise water, and Italian architects, keenly alert for means of effecting fountain displays then in vogue for villa gardens, were the first to attempt practical applications of the idea. This happened about the middle of the sixteenth century. Italy set the architectural style for Europe in that period, and Solomon de Caus, a French architect and engineer, while in Italy for ideas, became interested in the steam-operated fountain. On his return to France he began experimenting and both talked and wrote about the possibilities of steam, advancing a proposition for utilizing high-pressure steam. His enthusiasm seems to have broken down the last objection to experimentation and during the succeeding 100 years philosophers, the clergy, and engineers all over Europe were intensely busy.

The Italian chemist, Branca, used a jet of high-pressure steam to turn a paddle wheel. Kircher, a Jesuit and teacher of philosophy at Rome, designed a fountain and forced the water by steam pressure to unusual heights. The English bishop Wilkins, a brother-in-law of Oliver Cromwell, made many and varied experiments with aeolipiles and even advanced steam propositions in his sermons.

These experimenters had just about reached the limit of possible developments with the resources at hand when, around 1650, two discoveries were made which, although they had nothing to do with steam directly, had a very important bearing on the subsequent development of the steam engine. They were the inventions of the mercury barometer by the Italian, Torrecelli, a pupil of Galileo, and of the air pump by Von Guericke, the burgomaster of Magdeburg, Germany. By the former it was definitely proved that the atmosphere had weight and by the latter that air could be excluded at will from a closed vessel so as to obtain a vacuum. Von Guericke went further and rigged up a vertical cylinder with a piston, connecting the latter by a cord and overhead pulley to a weight. He then exhausted the air under the piston with his air pump and immediately the piston moved downward, lifting the weight.

Thirty years more passed and then Huygens, the Dutch astronomer, improved on Von Guericke's idea and obtained a vacuum under a piston without an air pump. He fitted up a cylinder with nonreturn valves and exploded gunpowder under the piston. Most of the gases escaped but as the quantity remaining in the cylinder cooled a vacuum was created and the piston went down just as with Von Guericke. Both of these experiments demonstrated that the weight of the air was capable of doing mechanical work. In 1690 Papin, a French

engineer, showed how steam could be used to obtain the vacuum. He also invented the safety valve and proposed to apply steam to draw water from mines, to shoot bullets from cannon, to propel boats, and to do many other things. He did not construct any practical

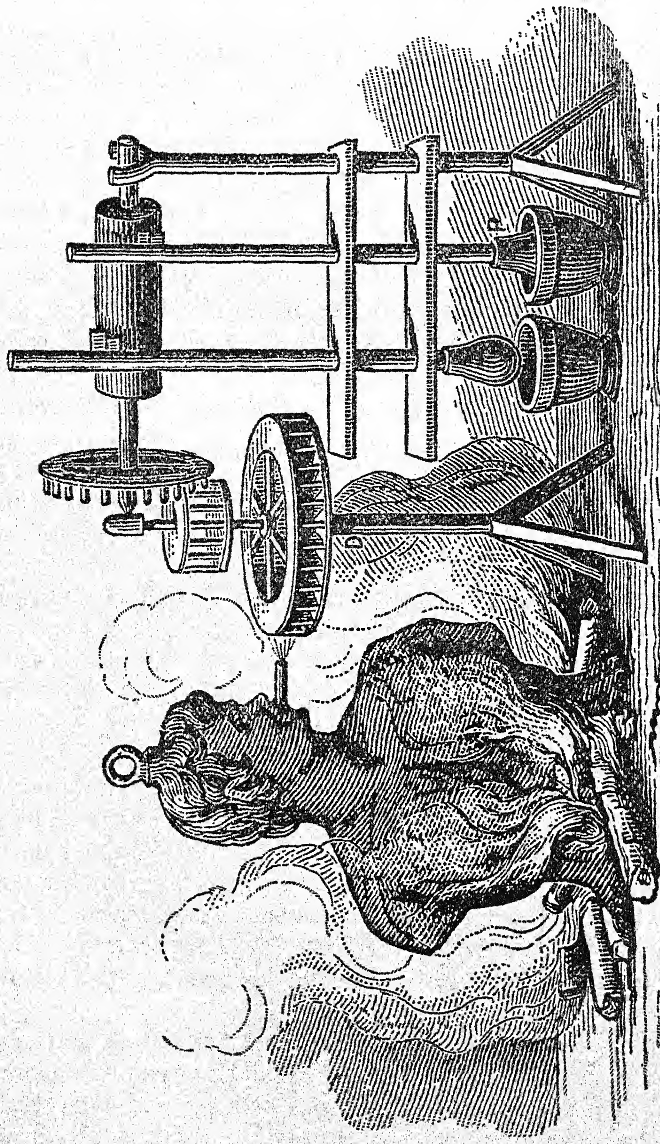


FIGURE 2.—Branca's steam engine, 1629 A. D. Giovanni Branca, an Italian chemist, suggested a device such as this for using steam to produce power. While a wasteful method, the idea was later modified and resulted in the modern steam turbine

engines, however, and came no nearer than his predecessors to solving the problem of making the piston move up and down continuously.

Necessity produced the next invention. England was experiencing more and more trouble keeping water out of her coal mines. The

pumps had been increased in size, gradually, until toward the close of the seventeenth century the largest which man or beast could proficiently handle were being used. Here then was a definite need for more power. Hero, Porta, De Caus, Huygens, and Papin had contributed all the rudiments for a power machine which simply awaited the touch of some mechanical magician to form a complete structure. That touch was given in 1698 by Capt. Thomas Savery. He was an English coal-mine owner and operator. In the year cited, he constructed and patented a machine for raising water "by the impellent force of fire." This represents the first attempt to utilize fuel as a practical means of doing mechanical work. His engine was not in actual service, however, because no one knew how to make boilers and pipes strong enough to resist the steam pressure necessary to raise the water from the deeper mines.

But before discouragement could set in, Thomas Newcomen, an ironmonger and blacksmith of Dartmouth, England, came forward in 1712 with his atmospheric steam engine, one of the most remarkable inventions of any age or time. From this, the growth of the modern steam engine is definitely traced. Newcomen had the same old vertical cylinder and piston but he injected cold water into the cylinder to condense the steam, and added a valve gear which enabled the engine to keep up its motion as long as steam was provided. Then began the age of steam and the steam engine, for the later developments of which the world is indebted to Watt, Evans, Corliss, De Laval, Parsons, and many others.

II. HOW THE STEAM ENGINE CAME TO AMERICA

Newcomen had no trouble getting orders for his engines after he had demonstrated what they could do. He employed additional help both to make and erect them. One of his best erection engineers was Joseph Hornblower, who assisted him when he installed one of his first engines in Staffordshire. Hornblower had two sons, Jonathan and Josiah, both of whom followed in their father's footsteps as engineers and were engaged with him, about 1748, in constructing Newcomen "fire engines."

One day Jonathan received word to come to London to meet the local agent of an American colonist. The result of this meeting was that the Hornblowers consented to build and erect an engine at the copper mine of Col. John Schuyler in New Jersey. Schuyler's mine at Belleville, near Newark, was the only one in the colonies and from it ore had been shipped to England for 25 years or more. With the lowering of the mine shaft water came in in such quantities as to tax the pumps to their limit. In this connection Benjamin Franklin wrote to a friend in February, 1750: "I know of but one valuable copper mine in this country, which is that of Schuyler's, in the Jerseys. This

yields good copper, and has turned out vast wealth to the owners. I was at it last fall, but they were not then at work. The water has grown too hard for them, and they waited for a fire engine from England to drain their pits. I suppose they will have that at work next; it costs them £1,000." As a matter of fact the engine cost three times this amount by the time it was erected.

Four years or more passed before the completion of the engine. When it was shipped Josiah Hornblower, then about 25 years old, went

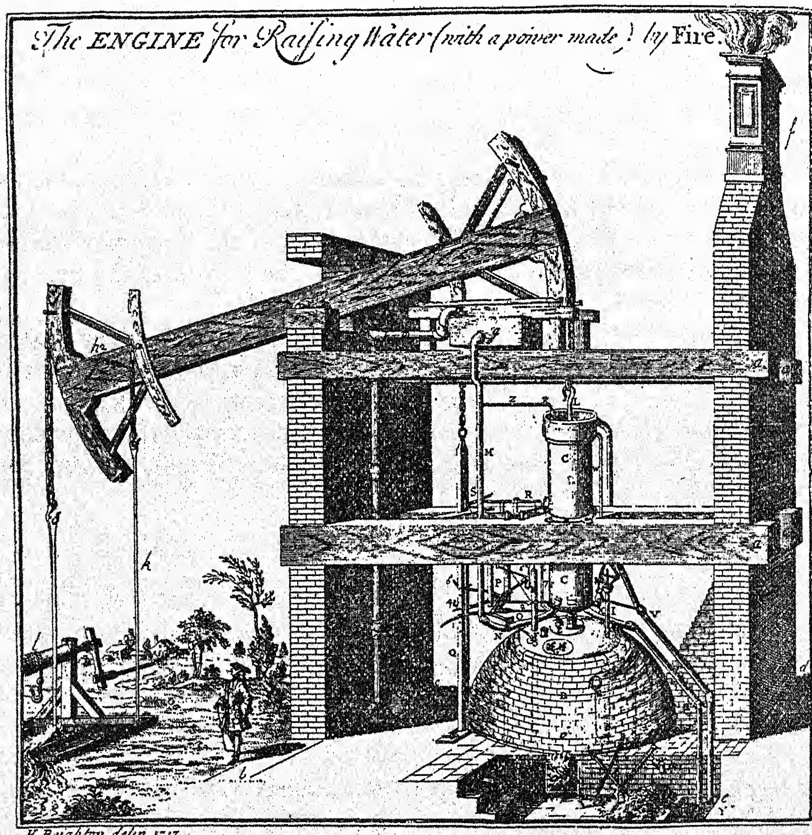


FIGURE 3.—Newcomen atmospheric engine. Introduced about 1712 and the first to embody on a practical scale some important features of the reciprocating steam engine. The original of this illustration was discovered in 1925 and indicates that as early as 1717 the engine had been improved by adding the automatic valve gearing perfected by Henry Beighton. (Courtesy of the Newcomen Society)

with it. America's first steam engine and power engineer landed in New York about September 9, 1753. "To cash pd. for 7 days, carting ye engine & boards to ye mine" is an item in the account books under the date of September 25, 1753. Then, with the engine in pieces at the mine, Josiah had his first opportunity to consider the

job ahead. It is perhaps a wonder that he did not take the first boat back to England. There was no skilled help for him to call on, no one who had the slightest idea of steam-engine construction. Accordingly he had to instruct as the work progressed. This all took time, and 18 months or more passed before the engine was ready to be steamed up early in the spring of 1755.

On this eventful day, when the first steam engine in America was to be set in motion, an interested group of colonists came to the mine. They saw standing on the very edge of the shaft an odd looking stone building, shingle-roofed, some 20 to 30 feet square and 30 feet high. Sticking out through one wall and over the mine opening was a heavy beam terminating in a vertical arc, like an enormous carpenter's hammer with the claw sticking upwards holding between its prongs a pump rod which disappeared down into the mine. Entering the engine house, the visitors beheld a roaring furnace and over it a spherical copper boiler 10 feet in diameter, partly inclosed in brickwork. Looking higher, they saw directly over the boiler and connected to it by a short pipe, a huge cast-iron cylinder, 3 feet in diameter and 8 feet high, supported on heavy wooden beams, stretching across and anchored into the building walls. Still higher rose the piston rod, connected by links to another huge claw hammer on the inner end of the same heavy beam that the visitors first observed. Near the cylinder, but several feet above it, they saw a small water tank from the bottom of which descended a small pipe with two branches, one going over the top and the other into the bottom of the cylinder, the first to form a water seal between the piston and cylinder wall to hold in the steam, and the second to supply condens-

FIGURE 4.—Josiah Hornblower, 1729–1809. The pioneer in the use of steam in America

ing water. Lastly their eyes rested on a series of ropes and valve handles on a board within easy reach from the floor.

The fluttering of the safety valve showed that steam was up. Josiah Hornblower took his place at the control board, undoubtedly nervous because of the importance of the occasion, and yet with confidence opened the steam valve between the boiler and the cylinder. Steam rushed in filling the cylinder. Another handle was turned and water from the overhead tank spurted into it, condensing the steam and creating a vacuum. All this time the piston remained still at the top of the cylinder. Now, however, atmospheric pressure bore down on the piston head, forcing it downward and pulling with it the inner end of the big walking beam and raising the pump rod attached to the other end outside. Hornblower had so skillfully calculated the weight of the pump rod and water to be pumped at one end of the beam and the weight of the piston and air pressure at the other end that the weight of the air was just a little more than enough to lift the water from the mine. Other handles were then turned, steam again entered the cylinder and the pump rod descended by its own weight into the mine, pulling up the piston to its first position. Again steam was condensed and down went the piston and up went the pump rod. So it kept going, 10 to 12 strokes a minute and lifting 10 gallons of water with each stroke. And so America's first steam engine was put in operation.

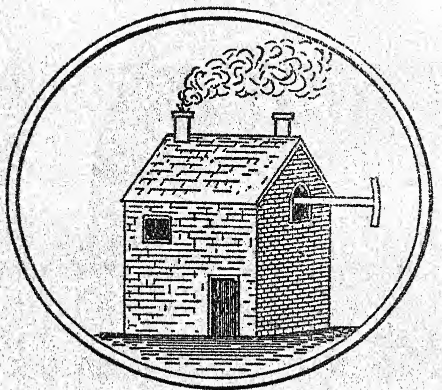
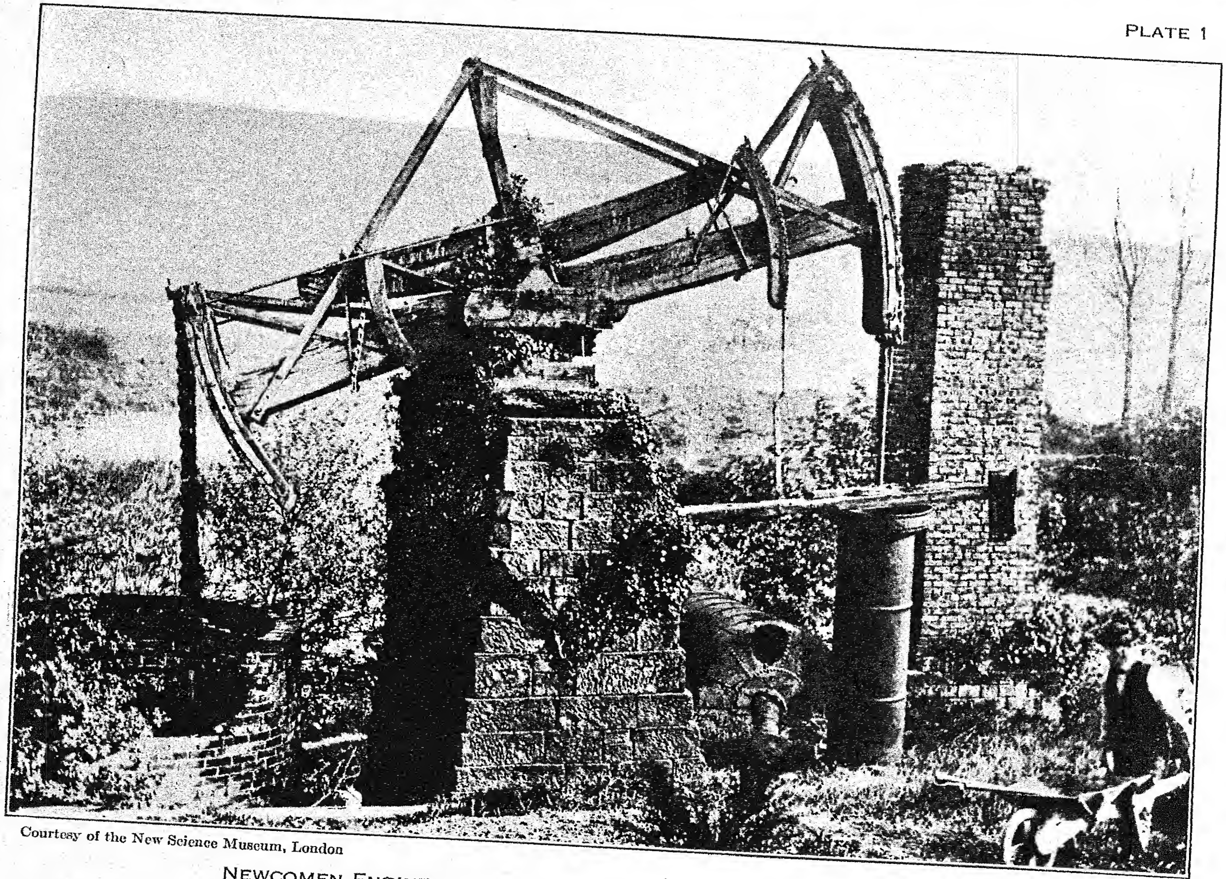


FIGURE 5.—Hornblower family seal. This illustrates the building which housed the Newcomen engine built in England by Joseph Hornblower and erected by his son Josiah in 1755 at the Schuyler copper mine, North Arlington, N. J. (Courtesy of the Delaware and Hudson Company)

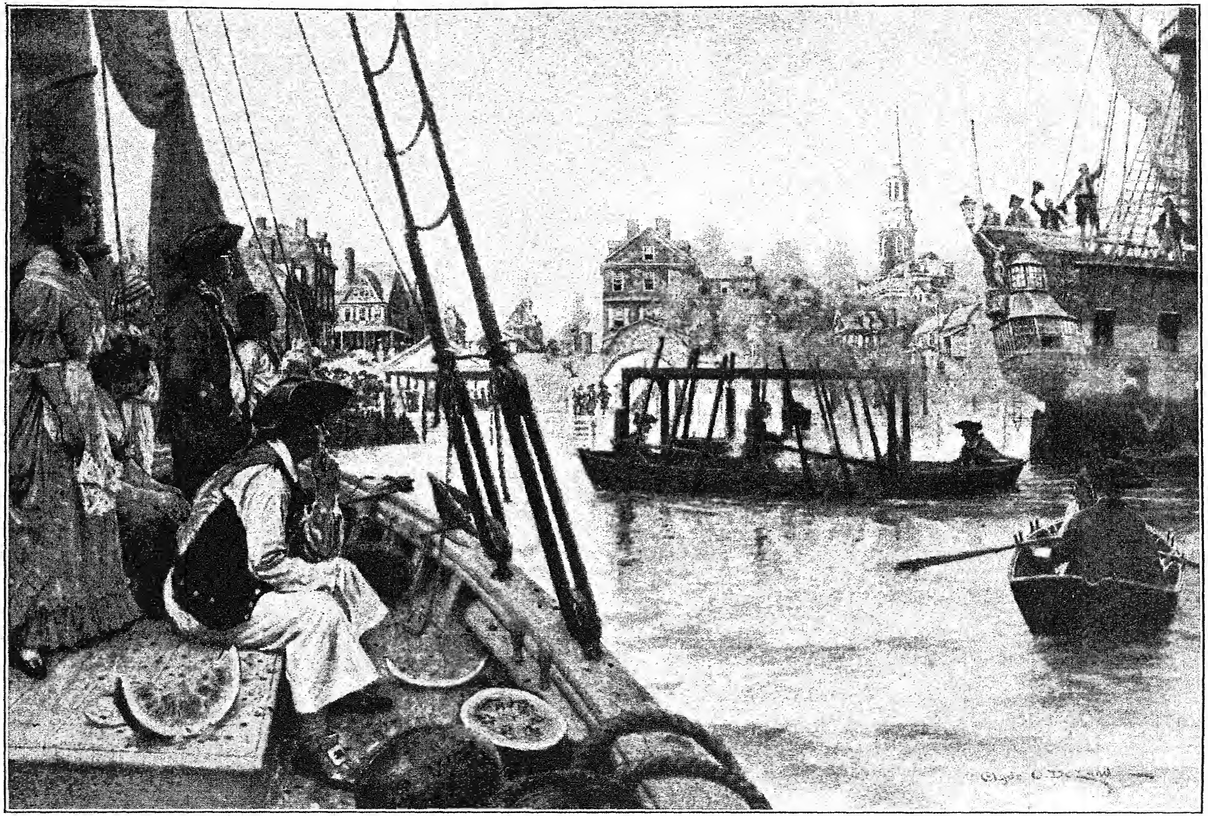
Hornblower's task was now successfully accomplished and he could have returned to England. Two things deterred him, however—the memory of the bad trip over and, more particularly, an interest in a very attractive girl of Belleville. Instead of going home he decided to accept Colonel Schuyler's offer of the superintendency of the mine and thereupon married Miss Kingsland. He operated the mine for 5 years then leased it from the owner for 14. He had rather indifferent success in operating it by himself so that when the power house burned down and greatly damaged the engine in 1768, the mine was abandoned. Hornblower then turned to civic affairs, became a member of the New Jersey Assembly and later an influential member of the Continental Congress. In 1793 another attempt was made to operate the Schuyler mine, and Hornblower again put the engine into shape. But the effort



Courtesy of the New Science Museum, London

NEWCOMEN ENGINE IN FAIRBOTTOM VALLEY, LANCASHIRE, ENGLAND

Photograph taken about 1860. The engine is said to have been built in 1750 and operated until 1827. Note its size as compared to the man in the right-hand lower corner.



Courtesy of the Continental Insurance Co.

FITCH'S STEAMBOAT TRIAL TRIP, AUGUST 22, 1787

This public demonstration was made on the Delaware River at Philadelphia, Pa. (From a painting by Clyde O. Deland.)

met with indifferent success, and around 1800 the engine was dismantled and its parts scattered. Years later the cylinder was found and cut in two by a man in need of a short length of pipe. The upper half not used was eventually obtained by the New Jersey Historical Association, which organization in 1889 presented it to the United States National Museum where it has been carefully preserved ever since.

III. STEAMBOAT PIONEERING

The Newcomen engine at Schuyler's mine failed to create any great amount of public comment or excitement. Its only use was to pump water and there was no other mine in the colonies requiring such a contrivance. In 1774, however, the common council of New York City, faced with the problem of increasing the city's water supply, accepted the proposal of an English engineer, Christopher Colles, to build a reservoir and install a Newcomen-type steam engine to pump the water. An engine was purchased in England and erected in 1776 but its capacity proved too small. Then the war came on and caused the whole enterprise to be abandoned.

Meanwhile, the colonies continued to spread up and down the Atlantic coast and along the navigable rivers which flowed into the ocean. Communities sprang up inland. Improved communications both for purposes of commerce and for the political unity of the federation became a necessity. Along the coast it was as yet out of the question to travel very extensively overland so that practically all intercourse was had by sailing vessel, a very slow agency. To go inland meant to go upstream.

Amongst those who appreciated the seriousness of these conditions and gave of his time and money in an effort to better them was William Henry, the famous gunsmith, financier, and patriot of Lancaster, Pa. He believed that steam power could be used to operate a boat upstream and to prove his contention, he built an engine and stern-wheel boat in 1763 and tried it on the Conestoga Creek at Lancaster. The trials were unsuccessful as were those with a second and improved model. Henry made no further attempt after this because, as he remarked to a friend, "I am doubtful whether such a machine would find favor with the public, as every one considers it impracticable to make a boat move against wind and tide." Henry, however, must be credited as the first person in the United States to apply steam to propel a boat. Twenty years later, two men working independently again brought to public attention almost simultaneously boats propelled by steam. These men were John Fitch in Pennsylvania and James Rumsey in Virginia.

JOHN FITCH

John Fitch had reached his twelfth year when Hornblower got the Newcomen engine going in New Jersey. He had had a month or

two of schooling each winter since he was four and he much preferred reading and arithmetic to helping on his father's farm at East Windsor, Conn. By the time he was 13 he had progressed so far in mathematics that his schoolmaster told him "he could learn him no farther in arithmetic but would learn him in surveying." Fitch accordingly learned what he could of this profession and while he did not follow it up immediately it kept him from starving later in life. He had never been in robust health nor had he much physical endurance, so in his seventeenth year his father, somewhat disappointed, decided that he would either have to go to sea or learn a trade. One trip along the coast in a sloop decided Fitch against sailoring. He tried the other alternative, becoming a watchmaker's apprentice. Unfortunately, the two masters for whom he worked were averse to instructing their apprentices and after five years' effort Fitch gave up, almost as ignorant of watchmaking as when he began.

FIGURE 6.—John Fitch, 1743-1798. First to build and operate a man-carrying steamboat in America

From this time on until he died, every undertaking that Fitch attempted went wrong sooner or later. He went into the potash business and his partner absconded with all the funds; he married but the clash of natures proved too much for him and he abandoned his wife and children within two years; he tried button making in Trenton and the factory burned down; while surveying in Kentucky he was captured and held prisoner by Indians. After considerable hardship and suffering he was released and made his way to Buck's County, Pa. Here, in 1785 at the age of 42 he began his work on steamboats. From what he wrote later, the idea of utilizing steam force in any manner seems never to have occurred to him before this and he began his experi-

ments presumably with no information as to what had already been done with steam.

Between April and August of that year Fitch tried a number of schemes for propelling boats—endless chain, side and stern paddle wheels and screw propeller. He built four models equipped with a steam engine and one or another of the propelling devices and operated them successfully on a little stream near Davisville, Pa. The boiler was an iron kettle, the propelling machinery was made of brass and the paddle wheels of wood. By autumn he had spent all of his money. He determined to ask the assistance of the Continental Congress, then in session in New York. He presented his petition backed with commendatory letters from such men as Doctor Ewing, provost of the University of Pennsylvania, and Doctor Smith, provost of Princeton, but no action was taken. Quite discouraged he went back to Philadelphia and presented one of his models and a description of his invention to the American Philosophical Society. This time he received moral support but still no money. He then undertook to raise money through the sale of maps which he had drawn and engraved of the "northwest parts of the United States," posting a bond with Patrick Henry as an earnest of his good intentions. By setting aside one-half of the subscription price, a French crown, a little money was secured but hardly enough to build a full-sized boat such as he hoped to construct. He next turned to State legislatures for help and special privileges. The first approached, that of New Jersey, on March 18, 1786, granted him the exclusive right for 14 years to build and operate steamboats on all the waters of the State. Armed with this talking point, Fitch succeeded then in organizing a steamboat company composed of prominent Philadelphians, and with the money advanced by the stockholders plus what he had derived from the sale of his maps, he began work in Philadelphia. A steam skiff was tried out July 27, 1786, and a 45-foot boat begun shortly after. With the help of his friend, Harry Voight, who designed the steam boiler, he worked steadily on it for over a year, receiving his reward when a successful trial trip with the two aboard was made on August 22, 1787, on the Delaware River.

Twelve large wooden paddles, six in tandem fashion along each side of the boat, alternately dipping into and drawing out of the water much as the Indian paddled his canoe, propelled the boat at a speed of 3 miles an hour up and down the river. The up and down motion of the engine piston was converted into the peculiar motion of the paddles through sprockets, chains, and cranks. The engine operated on the Newcomen principle, including the injection of cold water into the cylinder to obtain the vacuum, but the cylinder and boiler were placed side by side in the boat rather than one on top of the other, as Newcomen arranged his engines.

The Federal Constitutional Convention, then in session at Philadelphia, had adjourned on this memorable afternoon so that its members might witness the experiment. They lined the water front cheering Fitch as he steamed past. Some even got a ride in the boat, amongst them Chief Justice Ellsworth of Connecticut.

Proud and happy as he was for having accomplished what everyone believed impossible and for being the first person in the United States to build and successfully operate a man-carrying steamboat, Fitch was disappointed with the boat's speed and immediately went to work on another one. He continued also to petition neighboring States for exclusive privileges such as New Jersey had granted him, and before the close of 1787, Pennsylvania, New York, Delaware, and Virginia had acceded to his request. How he managed to keep body and soul alive no one knows. He prevailed upon each member of his company to agree to a 30 dollar assessment to permit him to go on with the new boat which he completed in the summer of 1788. This boat measured 60 feet and was propelled by a paddle wheel at the stern turned by a small steam engine having a 12-inch cylinder. The trial trip of this boat, made in July of that year, was from Philadelphia to Burlington, N. J., a distance of 20 miles upstream, the greatest distance ever made by a steamboat up to that time. Fitch made many round trips in the course of the next few months. On one of these, his boat carried 30 passengers. Even with this load it made the trip up to Burlington in three hours and ten minutes.

While it is quite easy to imagine that the people who saw Fitch's boats might have looked upon his first one as a mere accident and his second but a little more than that, it is hard to understand their continued indifference after his third boat, larger than the others, was put into regular service on the Delaware River in 1790, and its schedule of sailings advertised in the Philadelphia daily newspapers. The Federal Congress at least had a change of heart, granting him a patent on August 26, 1791, for a term of 14 years, the original document having been signed by George Washington and by the commissioners Thomas Jefferson, Henry Knox, and John Randolph. Later on in the same year, the French Government likewise granted him a patent protecting his invention for 15 years. For many years the original of this French patent has been on public exhibition in the National Museum.

Fitch's desire for improvement in his steamboats was insatiable and given the opportunity, he would no doubt have made better boats. Unfortunately, neither the general public nor the Government could see the future of steam navigation even in the face of Fitch's accomplishments. He had the vision, but like many inventors before and since, he stood alone. The more he talked about the wonderful opportunities of this new mode of travel the more firmly convinced everyone became that he was really crazy.

After a fourth boat, which he began in 1791 and appropriately named *Perseverance* was almost completely destroyed by a violent storm at Philadelphia, Fitch's stockholders became totally discouraged and declined to advance any more money. In desperation he went to France, but in spite of the fact that he had a French patent for his steamboat the trip proved fruitless. Working his way as a common sailor, he returned to Boston destitute and worn. A brother-in-law found him there, brought him back to East Windsor, and took care of him for two years or more.

While a surveyor in Kentucky, Fitch had acquired some land at Bardstown and about 1797 he decided to return to Kentucky and claim it. On the way he stopped in New York long enough to try just once more to arouse interest in his invention. He built a small steamboat capable of carrying four people and operated it on Collect Pond, which once existed just off Broadway near City Hall. Again his efforts were in vain, and wholly discouraged he moved on to Kentucky. In 1798 he died, leaving a written request that he be buried on the shores of the Ohio so that he might repose "where the song of the boatmen would enliven the stillness of my resting place, and the music of the steam engine soothe my spirit."

Before he died Fitch prepared his own memoir, including an account of his experiments in steam, and bequeathed it to Franklin Institute at Philadelphia. It is the writing of a discouraged man whose moods, however, fluctuated as he went along. Near the beginning he wrote, "I know of nothing so perplexing and vexatious to a man of feelings, as a turbulent Wife and Steam Boat building. I experienced the former and quit in season, and had I been in my right sences I should undoubtedly have treated the latter in the same manner, but for one to be teised with Both, he must be looked upon as the most unfortunate man of this world." He closed the memoir with this, "The day will come when some more powerful man will get fame and riches from my invention, but nobody will believe that poor John Fitch can do anything worthy of attention." Just nine years later that reward came to Robert Fulton.

JAMES RUMSEY

The history of invention abounds with cases in which an inventor publicly presents his new idea, only to have others come forward with claims of priority to the invention. In most cases such claims have turned out to be based on nothing more substantial than a vague idea. James Rumsey, however, publicly demonstrated his independently conceived and worked-out idea of a steamboat on December 3, 1787, operating it on the Potomac River at Shepardstown, W. Va. This was just a little over three months after Fitch successfully demonstrated his Indian paddle steamboat at Philadelphia, so that while

priority seems to belong indisputably to Fitch, Rumsey deserves credit for independent and almost simultaneous invention. Rumsey was forced to make his demonstration to substantiate his claim of priority, which he had made just a month before in a petition to the Virginia Legislature asking for the repeal of the exclusive privileges which had been granted on November 7 to Fitch. A year later the committee appointed to consider Rumsey's petition reported a bill repealing Fitch's grant, but it was defeated in the House of Representatives, thus substantiating Fitch.

Rumsey came originally from Maryland, entering the world on his father's farm at Bohemia Manor, Cecil County, in the same year (1743) that Fitch was born. He attended the country school near his home and became quite interested in mechanics and when he was through school he immediately learned carpentry and blacksmithing. Later on he tried his hand as a millwright but neither in this nor in his other trades was he much of a success, for he was constantly puttering around trying to perfect mechanical contrivances of one sort or another, and worked at his trades only enough to keep from starving. After the Revolutionary War, in which he served, he settled on the banks of the Potomac River at Bath, Berkeley County, Va., which is now Berkeley Springs, W. Va. With a partner he opened a general merchandise store, and, also because of his general mechanical ability, served as a bath tender, for even as long ago as 1780 Bath or Berkeley Springs was quite a health resort.

In spite of himself, however, Rumsey could not resist the temptation to tinker. It was not long before he left the store business entirely to his partner and spent most of his time working by himself. He maintained the utmost secrecy about his work and when asked what he was doing he answered vaguely with an air of mystery so that he became known locally as "Crazy Rumsey." He was, however, by no means as crazy as people thought.

For many years the problem of inland transportation had the attention of all progressive colonists. Long after the first settlements were established along the Susquehanna, Schuylkill, and Potomac Rivers and beyond the Alleghenies, the settlers continued dependent almost wholly on goods sent from the colonies along the eastern coast. Decent roads did not exist and nearly all commerce went by river. All manner of boats were developed for hauling freight, but the most common was a heavy keel boat or "Durham" boat, which resembled a scow with a freight car perched in the middle. A running board stretched the whole length of each side of the boat. On this the crew walked from bow to stern pushing with their shoulders on poles set in the bottom of the river. The expense of carrying freight "west" in this way proved tremendous. It required a crew of anywhere from 4 to 10 men to pole one of these boats, their wages and living expenses

had to be paid, the distance covered in a day was small, and the amount of cargo carried was hardly noticeable.

Rumsey knew all this, for the Potomac River, on which he lived, served as one of the main waterways west. He knew also that General Washington was greatly interested, because of his large holdings in the Ohio Company organized by his half brothers Lawrence and Augustine, to which he had fallen heir. This company owned large land areas in the Northwest Territory and engaged in the fur trade. Sometime in the early summer of 1784, therefore, Rumsey wrote Washington that he had perfected an idea for mechanically propelling boats upstream, and invited him to stop over at Bath the next time he came that way to witness a demonstration of a working model of the scheme. Washington accepted the invitation and on September 5, 1784, Rumsey showed him his model, but only after the General had promised not to divulge the principle involved. In his diary, on September 6, 1784, Washington wrote, "The model and its operation upon the water, which had been made to run pretty swift, not only convinced me of what I had before thought next to, if not quite impracticable, but that it might be the greatest possible utility in inland navigation; and in rapid currents. What adds vastly to the value of the discovery, is the simplicity of its works; as they may be made by a common boat builder or carpenter, and kept in order as easy as a plow or any common implement of husbandry on a farm." This was Rumsey's first boat. It was pushed by mechanically operated poles, but the power used was not steam.

Encouraged by Washington's evident enthusiasm, Rumsey worked on his model for several months more and then abandoned it when another idea, that of using the force of steam, came to him. He again wrote to Washington on March 10, 1785, "I have taken the greatest pains to perfect another kind of boat, upon the principles I mentioned to you at Richmond in November last * * *." He refrained from telling what the principle was, for fear of having it stolen, but it involved pumping a stream of water, under pressure, out through the stern of a boat below the water line, the reactive force resulting causing the boat to move forward. It was a boat thus propelled that Rumsey used in his first public trial in 1787, mentioned earlier.

Alone and behind locked doors, Rumsey experimented with his new scheme off and on, throughout the spring of 1785. He could not spend all of his time on it, however, for he was in charge of operations for a company that had just been formed by Washington to improve the navigation of the Potomac. About May the news came to him that Fitch had started experimenting with steamboats and he knew then for the first time that he had a rival and that he would have to hurry. He decided to build a full-sized boat and hired a local mechanic,

Joseph Barns, to help him. He felt too, that now more than ever before it was imperative to do everything in secret, and having obtained Barns' cooperation in this, the latter was set to work building the boat. When it was completed in September, Rumsey sent him to Baltimore and Frederickstown, Md., to have the steam cylinder, boiler, and other machine parts cast and made. By the time these were completed winter had set in forcing the temporary abandonment of the work.

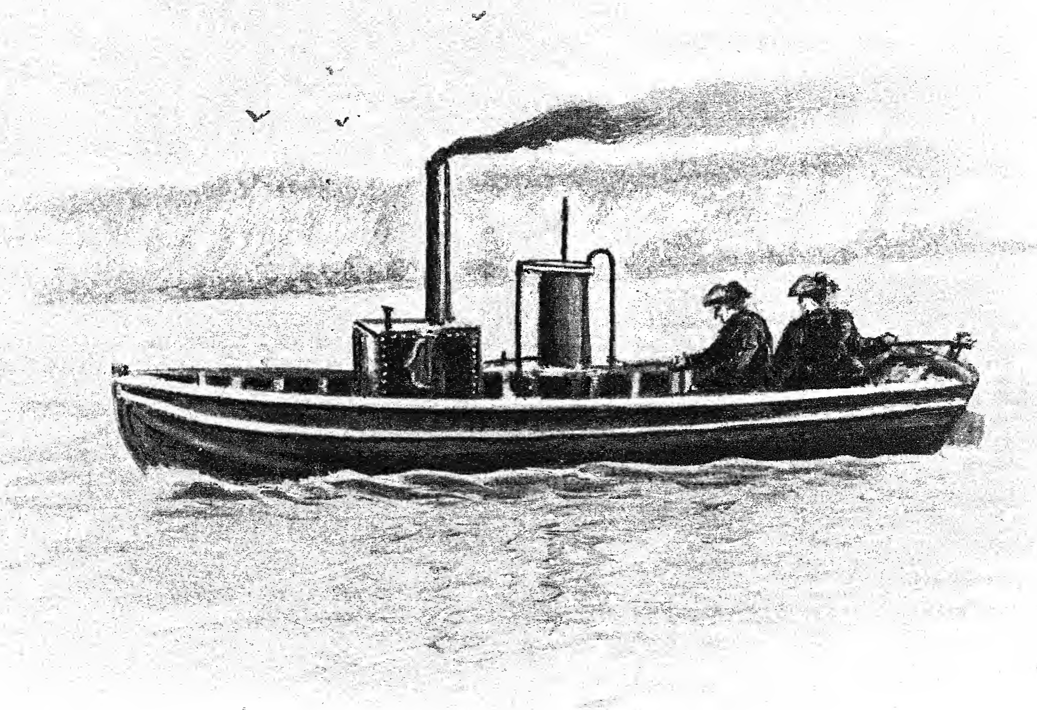
Evidently Rumsey wrote to Washington from time to time telling him of his progress. Like Fitch, he had no money to speak of, but with Washington's indorsement of his project he believed that obtaining funds would be the least of his troubles. Washington gave him a real scare in a letter written in January, 1786. After advising him to place his boat before the public as soon as possible, he told Rumsey that "many people, in guessing at your plans, have come very near the truth, and one who has something of a similar nature to offer to the public, wanted a certificate from me that it was different from yours." Rumsey felt sure that the person referred to was Fitch.

Soon after the ice went out of the river in the spring Rumsey and Barns secretly tried out the new boat, but so many of the machine parts were defective that the experiment failed. Throughout that year they worked on it, changing the machinery, devising a new boiler, and trying out other ideas that came to them. Another secret trial was made in December, 1786, but no better results were obtained and then, to cap the climax, one December night drifting ice carried the boat away. Rumsey recovered it but both boat and machinery had suffered such damage that they could not be gotten ready for another trial before September, 1787. This time the boat moved by the force of steam against the river current with a speed of about 2 miles an hour. Though the machinery proved far from satisfactory, Rumsey took great encouragement. With Barns' help he put the machinery into the best possible shape and staged a public demonstration on December 3, 1787. This turned out to be the best trial made. It gave the people from Bath and Shepardstown their first opportunity to see what Rumsey had been doing.

As mentioned earlier, the boat was moved by forcing water out of the stern. Rumsey's outfit to do this consisted of a steam boiler, a cylinder, and a pump, all in the forward part of the boat, the boiler nearest the bow. The cylinder and pump were bolted together, one on top of the other—the pump underneath—with the pump plunger and piston having a common rod. Steam was used only in the cylinder under the piston where it was treated the Newcomen way, making an atmospheric steam engine. The pump had two openings, one to admit river water through a pipe coming up through the bottom of the boat, and the other connected to a pipe or "trunk," as Rumsey called it, running back along the bottom of the boat through the stern.

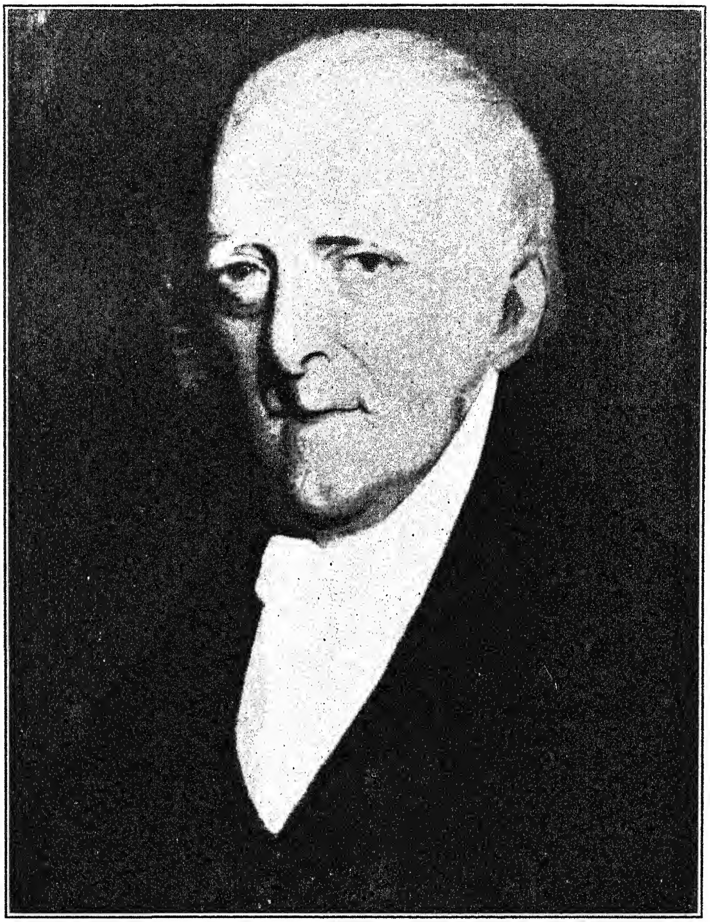
JAMES RUMSEY, 1743–1792

Designer and builder of the second man-carrying steamboat in America.



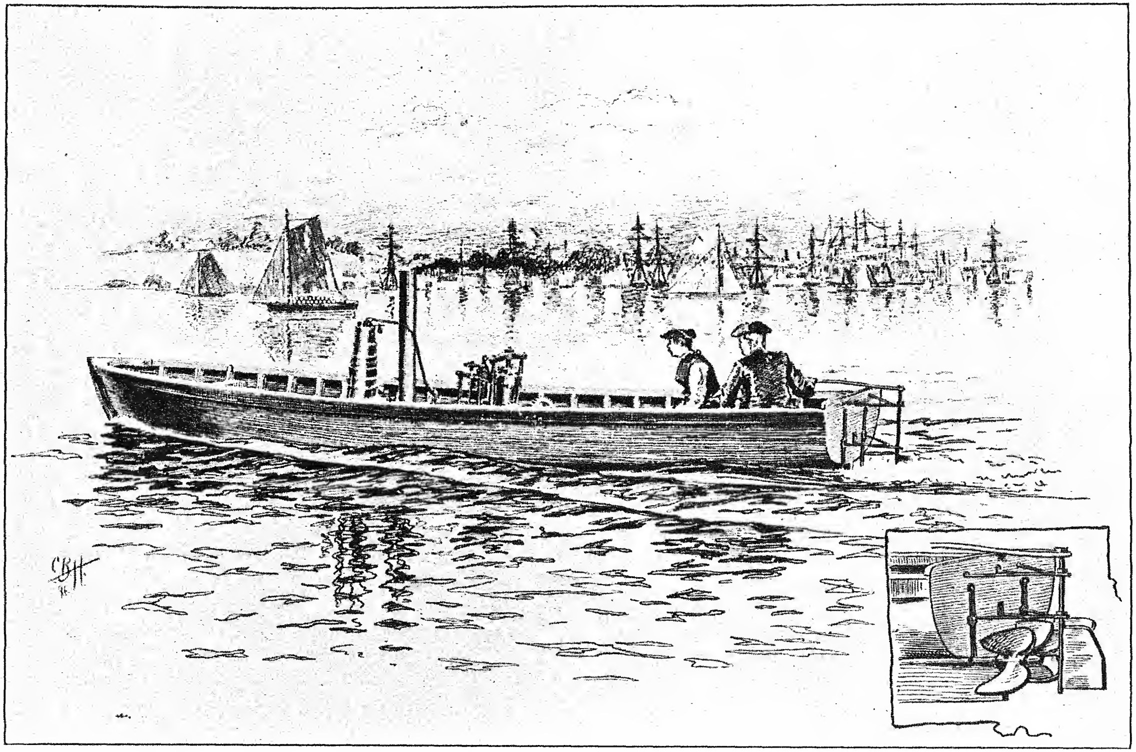
RUMSEY'S FIRST STEAMBOAT TRIAL, DECEMBER 3, 1787

This public demonstration was made on the Potomac River at Shepherdstown, W. Va.



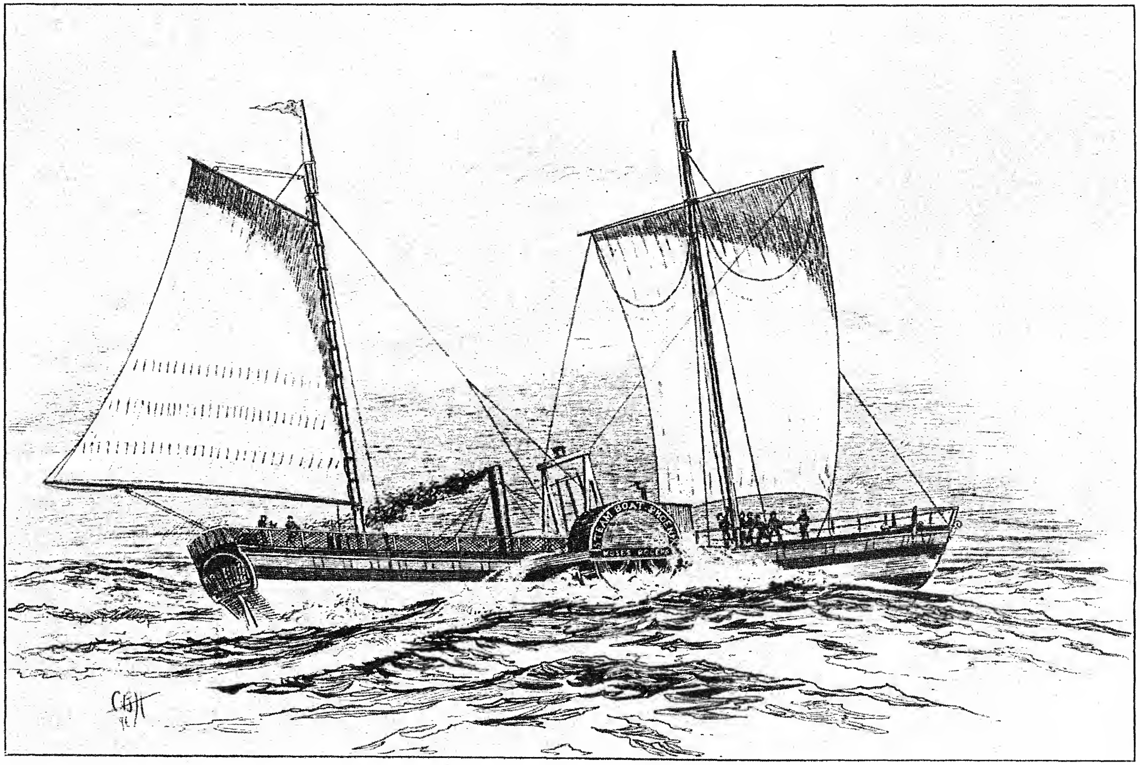
JOHN STEVENS, 1749–1838

The leading pioneer of his day in transportation, a genius with steam, and the builder of both steamboats and locomotives.



STEVENS'S STEAMBOAT "LITTLE JULIANA," 1804

This steamboat equipped with two propellers was successfully operated on the Hudson River in May, 1804, by Stevens's sons, Robert and John. The engine, boiler, propellers, and rudder are now in the National Museum.

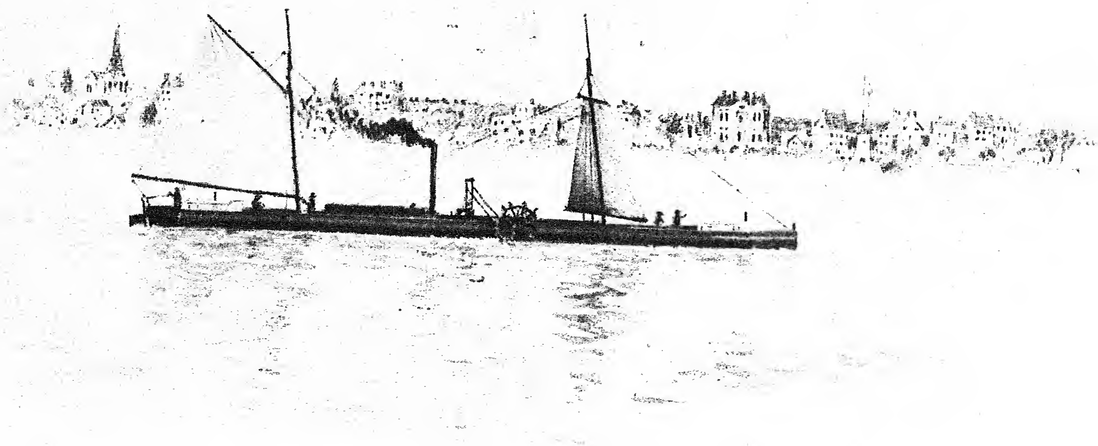


STEVENS'S STEAMBOAT "PHOENIX" AT SEA, 1809

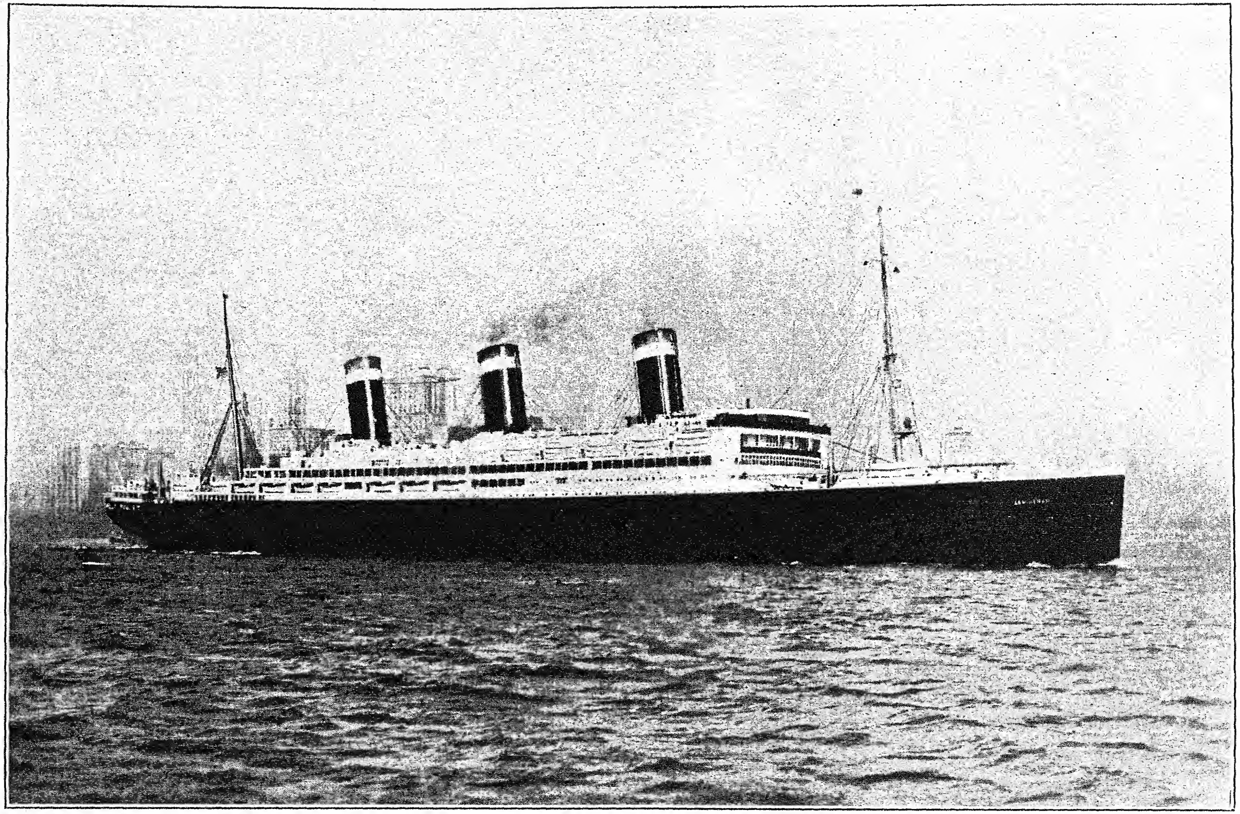
Designed and built in 1808. Because of Fulton's monopoly on the Hudson River, Stevens decided to send the *Phoenix* to Philadelphia. This was successfully accomplished by his son Robert and marked the first passage of a steamboat upon the open sea.

ROBERT FULTON. 1765–1815

Artist and engineer, and designer of the steamboat *Clermont*. The voyage of this vessel from New York to Albany and return in 1807 made steam navigation a commercial fact.



FULTON'S STEAMBOAT "CLERMONT," 1807
In the Hudson River opposite the Battery, New York.



Courtesy United States Lines

STEAMSHIP "LEVIATHAN," 1929

In the Hudson River opposite the Battery, New York.

Thus with each up-and-down stroke of the piston the pump plunger followed suit and alternately sucked in water through the bottom and forced it out at the stern, causing the boat to move ahead.

By this time Rumsey had used up all his money and set about first to secure exclusive rights from the various State assemblies and then to try to organize a company. Everywhere he went, however, he found not only that Fitch had preceded him, but also that many people were rather skeptical about him and his work. He began to realize the injury he had brought upon himself by doing his experimental work secretly. In 1788, however, he succeeded in forming with a group of Philadelphians the Rumseian Society to further his schemes and in May of that year the society sent him to England, thus leaving the United States to Fitch. He took out two patents in London and had a boat built which was tried out on the Thames in the autumn of 1792. Just how successful this trial was is not known. Rumsey continued experimenting into December, when with hardly any warning, he had a stroke of apoplexy and died on December 23, 1792, only 49 years old. Where he died or was buried in London is not definitely known. His perseverance in the face of all sorts of ridicule won for him the honor of being the second man in the United States to successfully propel a boat by steam power. Years afterward the Kentucky Legislature presented a gold medal to Rumsey's son in commemoration of his father's service.

Regrettable as were the tragic deaths of America's first two steamboat pioneers, their work was not in vain. They were looked upon by the majority as nuisances and victims of "steam mania," yet their efforts impressed a few serious-minded persons sufficiently to insure the continuance of experiment. Without them the successful steamboat would not have been an accomplished fact so soon.

JOHN STEVENS

Col. John Stevens owed his interest in steam power to John Fitch. While driving along the banks of the Delaware River near Burlington, in 1788, he saw Fitch's steamboat pass up the river against the tide. He followed the boat to its landing, where he got aboard and examined the engine and propelling paddles carefully. From that hour he became an unwearied experimenter in the application of steam power. Fortunately, too, he had ample private means so that he could afford to experiment.

Stevens was born in New York City in 1749, the son of John Stevens, distinguished for his public service in the New Jersey Colony. After graduation from King's College (now Columbia University), in 1768, young Stevens took up the study of law but never practiced. He served in the Revolution as colonel of his own regiment until New Jersey called him to act as treasurer of that Colony. During

the succeeding fifty-odd years Stevens lived in New York and on his estate across the Hudson in Hoboken. At the latter place he carried on all his experimental work with steam.

It will be recalled that in 1786 New Jersey had given Fitch a 14-year exclusive privilege to make and operate steamboats in the State. Stevens first petitioned the State legislature in 1788 for permission to place a steam engine on board a boat for experimental purposes. He then undertook an intensive study of the whole subject of steam, devoting upwards of two years to it until he had thoroughly familiarized himself with both its history and its practical applications. Stevens took out his first steamboat patents in 1792. They called for the propelling of vessels by a steam engine modified from the original steam pumps of Captain Savery, of England. During the succeeding six years he made many experiments on different modes of propulsion by steam, but, like Fitch and Rumsey, he was hampered by lack of facilities, both in men of mechanical ability and in tools.

In this connection Nicholas Roosevelt, another New Yorker, seems to have been the first man to engage in machine work in the United States. In 1794 he, with two partners, purchased 6 acres of land at Belleville, N. J., from Josiah Hornblower and erected a foundry and machine shop there. But the work they were able to do seems pitiful to us now. For instance, the city authorities of Philadelphia in 1800 sent them a steam cylinder in two sections, each 38½ inches in diameter and 3¼ feet long to be bored. This was for use in the Boulton & Watt steam pumping engine, which Philadelphia had imported from England several years before for the city water pumping plant. Roosevelt started work with his boring machine operated by water power on April 9. Two men were in attendance day and night, "one almost living in the cylinder," and the job was completed four and one-half months later. Had they had the handling and machine-tool equipment of 1929 the cylinder could have been bored in 24 hours.

Stevens' absorption in steam experiments seems to have been rather contagious, infecting particularly his brother-in-law, Robert R. Livingston, one of the richest men of his time and chancellor of New York State. He apparently fought it off as long as he could but finally succumbed in 1798, when he acquired Fitch's New York State rights to steam navigation. He wanted to build a steamboat immediately, and had more or less made up his mind to order a steam engine from James Watt in England, but Stevens and Roosevelt who were associated with him, dissuaded him from doing that, and instead prevailed upon him to let Roosevelt build the engine at his shop in Belleville. Roosevelt at that time had in his employ two Englishmen, John Smallwood and John Hewitt, the former a machinist and the latter a draftsman and patternmaker, who had been sent to Philadelphia by Boulton

& Watt to erect their pumping engine and who, like Hornblower, decided to stay in America. With the knowledge of steam engines possessed by these two and with the help of a German, named Rohde, who could make castings, Roosevelt felt pretty confident that he could build an engine for Livingston's boat. And so he did. The boat, 60 feet long, with a 20-inch cylinder and 2-foot stroke, made her trial trip in October, 1798, but it was not successful in spite of the fact that the steam engine used had all of Watt's wonderful improvements. The fault lay in the propelling mechanism suggested by Livingston. The next year another experiment was tried, this time from a plan of Stevens for a set of paddles in the stern with a crank motion, driving the boat forward as they rose and fell. With Smallwood, Rohde, Hewitt, and Stevens aboard, the boat steamed down the Passaic River from Belleville to New York and back, but the mechanism shook the boat so terrifically that this plan had to be abandoned.

By this time Livingston's ardor had cooled somewhat, for the experiments had failed to meet the terms of the franchise granted him by New York State relative to speed. He dropped out and shortly afterward went to Paris as United States minister to France. Stevens, however, was more determined than ever to solve the difficulties. He designed and built a rotary steam engine to be used with a screw propeller. He placed this combination in a little 25-foot boat in the summer of 1802, and used it occasionally in crossing the Hudson between New York and Hoboken. About this boat Stevens wrote: "She occasionally kept going until cold weather stopped us. When the engine was in the best of order, her velocity was about 4 miles an hour." The engine, while very simple, was hard to keep steam-tight. That winter Stevens resorted again to the reciprocating engine.

Stevens had by this time made himself probably the best engineer in America. Early in 1802 he designed, built, and sold to the Manhattan Co., proprietor of the waterworks of New York City, a Watt type steam engine for operating the water pump worked up to that time by horses. Engine and pump handled 500,000 gallons of water every 24 hours. Yet his studies and experiments with steam extending over a period of 20 years had not produced a really successful steamboat. The obstacle consisted undoubtedly in the lack of tools and metal-working equipment. His 1802 experiment showed great promise, however, and in 1804 with the help of his 17-year-old son Robert, he launched and successfully navigated in New York Harbor the first twin-screw-propellered steamboat, operated by a high-pressure, reciprocating steam engine and multitubular boiler, both of his own design. The boat was a small one, hardly more than 25 feet in length. In its trips back and forth across the Hudson it attracted much attention.

Dr. James Renwick, who was at that time professor of natural philosophy at Columbia University, in telling of the time he saw the boat, wrote: "We went to walk in the Battery. As we entered the gate from Broadway we saw what we in those days considered a crowd running toward the river. On inquiring the cause we were informed that Jack Stevens was going over to Hoboken in a queer sort of boat. On reaching the bulkhead we saw lying against it a vessel about the size of a Whitehall rowboat in which was a small engine, but there was no visible means of propulsion. The vessel was speedily under way, my late much-valued friend, Commodore Stevens, acting as cockswain; and I presume the smutty-looking personage who fulfilled the duties of engineer, fireman, and crew, was his more practical brother, Robert L. Stevens." The engine, boiler, and propellers of this historic steamboat still exist. Stevens Institute at Hoboken, founded by Colonel Stevens' son Edwin, took care of them until 1893, when they were presented to the National Museum, where they have been carefully maintained and exhibited ever since.

Stevens had now designed and built four types of steam engines—the steam pump after Savery, the Watt type with separate condenser, a rotary, and a high-pressure, noncondensing type. With all of them he had tried to propel boats. All were crude affairs and none could be said to have given convincing proof of the feasibility of steam navigation. He knew his engines were crude and he had the money to pay for the best, but steam-engine building did not exist in America as a trade until after 1800 and did not amount to much for some years thereafter. Stevens, however, decided to try once more and in 1806 began the construction of a large boat, 103 feet long, rigged with two masts and sails. It was equipped with a crosshead steam engine, with two condensing cylinders 16 inches in diameter and with 3-foot stroke. The boiler, set in brickwork in the bottom of the boat, consisted of a cylindrical shell with one return flue. The engine, in turn, operated a pair of side paddle wheels. Colonel Stevens had the *Phoenix*, as the boat was called, ready for trial in 1807, but no sooner was it afloat than it was debarred because of the monopoly granted by the State of New York to Livingston and Fulton for steamboat service on the waters of New York. Stevens decided to send the *Phoenix* to Philadelphia. In June, 1808, with his son Robert in command, the *Phoenix* made the trip by way of Sandy Hook and Cape May, the first sea voyage ever made by a steam vessel. On her passage she encountered a storm which damaged her somewhat and compelled her to seek shelter in Barnegat Bay. After reaching Philadelphia, however, the boat ran as a packet for six years on the Delaware River between Philadelphia and Trenton, and was finally wrecked at Trenton.

The performance of the *Phoenix* ought certainly to have brought to Colonel Stevens the greatest acclaim of his career, but, unfortunately, the feat was undertaken too late. As has often been the case before and since his time, public fancy rested at the moment on another (Robert Fulton) and so the accomplishments of the *Phoenix* passed almost unnoticed. One can not help but believe, considering Stevens's knowledge, ability, and wealth, that had he so wished he could have established at an early date a practical and commercially successful steamboat service, but his ambition was to make it a purely American colonial undertaking and he refused to purchase any foreign engines or other equipment.

Discouragement does not seem to have had a place in Stevens's makeup. He continued with his experiments although hampered somewhat by Fulton's monopoly. His years prevented him from taking as active a part as formerly, but he had in his son Robert an admirable successor. Robert Stevens soon became the foremost marine and railroad engineer in the United States. Within three years, in 1811, father and son had built a steam ferryboat and laid the foundation for the present extensive ferry system between New York and New Jersey. Thereafter and until his death at the age of 89 Colonel Stevens devoted the major part of his time and energy in fighting for the establishment of railways against canals, in the attainment of which his influence ranked high.

ROBERT FULTON

When Chancellor Livingston sailed for France to take up his duties as United States minister, he no doubt believed that he was leaving his interest in steamboats behind him. As a matter of fact his new post was to see that interest greatly increased, for shortly after his arrival in France he met Robert Fulton. From that meeting great results flowed.

Fulton was born in Little Britain, Lancaster County, Pa., in 1765. He displayed no more than the normal boy's interest in mechanics while in school but showed a marked aptitude in drawing. By the time he was 21 he had made quite a name for himself as a portrait painter. On the advice of a group of interested Philadelphians, in whose city he had lived and worked for a number of years, he went to England in 1786 to study under the patronage of Benjamin West, a noted Philadelphia artist then living in London. Through West, Fulton met many prominent people amongst whom were the Duke of Bridgewater and the Earl of Stanhope. Their interest in and discussions of engineering problems of the day so influenced Fulton that before long he, too, began thinking, studying, and talking of inland navigation and canal systems and forgot about his portrait work.

Fourteen years passed during which he was engrossed in experiments on submarine and torpedo inventions, in the hope of improving on the work begun in the United States during the Revolution by David Bushnell. Most of these 14 years were spent in Paris where Fulton lived with another American, Joel Barlow. It was there he met Robert Livingston, the new American minister. One can well imagine that before long the two were comparing notes on their several experiences with inland navigation problems, from which presumably came a revival of interest in steamboats. They became close friends and Fulton later on married Livingston's niece.

At all events, from his own personal knowledge of what English and French engineers as well as Rumsey had attempted in steam navigation, and after studying the drawings of Fitch's French patent, which he borrowed from Alfred Vail, the American consul, Fulton, with the help of Joel Barlow, who designed the boiler, built a steamboat in the spring of 1803. When he tried it out on the Seine, the hull unfortunately could not stand the weight of the machinery and it broke in two. Undaunted, Fulton immediately undertook the building of another boat, this time 66 feet long, and had it ready for trial in August of 1803, but it moved so slowly as to be altogether a failure. Having heard of William Symington's successful steamboat, *Charlotte Dundas*, which was put in operation in 1802 on the Forth and Clyde Canal, Fulton went to England in 1804, and obtained permission to make drawings of all of Symington's machinery. He proposed to go back to the United States to build a steamboat there and he wanted to have all possible data to take with him. In addition he began the movement to raise the ban then in force prohibiting the export of Boulton & Watt steam engines, for from his experiments he realized that his chances for success rested a great deal on the engine he should use, and Watt engines were then the best made. With the help of his influential friends, he succeeded in having the embargo raised. In 1806 he returned to New York with an engine and late in that year began the construction of the *Clermont*. Under his supervision the hull was built by Charles Brown, a shipbuilder of New York, the Boulton & Watt engine was put in place, and the whole made ready for its trial trip on August 7, 1807.

Fulton, a few friends, and mechanics, and six passengers were on board. An incredulous and jeering crowd gathered on shore as the boat cast loose at 1 o'clock in the afternoon. "Bring us back a chip of the North Pole" and similar facetious remarks could be heard by those on board as the nose of the *Clermont* was pointed north and up the Hudson. But, as the boat kept right on her way the attitude of those on shore gradually changed and great was the scramble for hats thrown high in the air by the cheering and no longer jeering mass.

Fulton's skill in selecting and combining the best mechanical equipment developed from the ideas of the foremost inventors of England, France, and America gave to the world the first practical and commercially successful steamboat. The *Clermont's* trip to Albany and return completely changed public opinion of the possibilities of steam navigation, and those who a few years before clamored for the maintenance of the old order of things were wondering a few years after how in the world one got along without steamboats. Fulton is to be honored for this achievement but not for the invention of the steamboat, a claim he personally never made.

IV. LOCOMOTIVE AND RAILWAY EQUIPMENT PIONEERS

Advocating steam railroads for the United States was a most heartbreaking experience for their first champions, Oliver Evans and John Stevens. Beginning in 1786 and for thirty-odd years thereafter, Evans hammered away in support of railroads on everyone from the members of the Federal Government on down, without having any apparent effect on anyone. He lost patience toward the end, especially when he saw that public sentiment tended toward the development of canals to augment highways, and in a public statement sarcastically wrote: "When we reflect upon the obstinate opposition that has been made by a great majority to every step toward improvement; from bad roads to turnpikes, from turnpike to canal, from canal to railways for horse carriages, it is too much to expect the monstrous leap from bad roads to railways for steam carriages at once. One step in a generation is all we can hope for. If the present shall adopt canals, the next may try the railways with horses, and the third generation use the steam carriage." Unfortunately he died without the satisfaction of knowing that the seed he planted and helped to cultivate grew and bore fruit.

OLIVER EVANS

Just prior to the time that Stevens took up the problem of steam navigation; in fact, about the time that Fitch was drawing fascinated groups to the banks of the Delaware as his boat steamed by, a fourth, and the youngest of the pioneer inventors in steam, began to attract real attention in Philadelphia. Unlike his three contemporaries who "lived and talked steamboats," Evans talked steam carriages. He never had the money to build one, but he did become America's first manufacturer of practical steam engines, introducing high-pressure types which by their lightness and cheapness were ideally suited to the needs of the simple colonial industries.

Evans was born in 1755 near Newport, Del., where his father was a farmer of moderate means and of respectable standing. He

attended school until he was 14 years old and then was apprenticed to a wheelwright or wagonmaker. Being much of a student he let no opportunity pass to acquire knowledge such as the books of the time afforded, devouring them by the light of a fire of wood shavings when denied candlelight by his illiterate and stingy master. As early as 1772, when only 17 years old, he had begun thinking of possible ways of moving wagons by other means than animal power.

FIGURE 7.—Oliver Evans, 1755–1819. Ardent champion of steam locomotion and founder of America's steam-engine industry

He was about to give up such ideas as unsolvable problems when his brother told him what some neighboring blacksmith's boys had done. They had stopped up the touchhole of a gun barrel, put in some water, rammed down a tight wad, and putting the breech in the blacksmith's fire were able to generate steam so that the gun discharged with a report like that of gunpowder.

To Evans, unacquainted with Huygens' experiment, this suggested a new source of power. He worked long in an effort to apply it and was again about to give up, when by chance a book describing the Newcomen atmospheric steam engine fell into his hands. Reading this revived his hopes somewhat, for he learned something definite of the properties of steam, and it gave him also some encouragement as to the merit of his idea of applying the expansive force of steam directly to move the piston. He even ventured to talk about steam power, but soon learned that it was rather unhealthy for anyone, least of all an insignificant apprentice, to talk openly about such absurdities.

For the next 8 or 10 years Evans tried his hand at different jobs, constantly looking for a chance to create some mechanical device to replace manual labor. At one time he did design a machine for pricking holes in leather to hold the teeth of a wool carder, but his big opportunity came in 1782, when his two older brothers who were millers, suggested that he join them in building a new flour mill near his home. It took four or five years to build, but when done the new mill was the only one in the country equipped with elevators, conveyors, drills, and a "hopper boy," all of Evans' design, for the mechanical handling of the grain, meal, and flour. With this equipment the mill could be operated by one man instead of the four who were needed in the old-fashioned mills.

Confident that his ship would soon come in, and even before the mill was finished, Evans petitioned the Legislatures of Pennsylvania and Maryland for exclusive rights on his flour-mill improvements, and also (it took a lot of courage to add this) to use steam wagons on the roads of the States. Pennsylvania granted the flour-mill rights in 1786 but made no reference to the petition for steam-wagon rights. The following year Maryland granted both requests, stating with regard to the steam wagon that "it would doubtless do no good, but certainly could do no harm." With these grants Evans and his brothers started out hopefully to sell their flour-mill machinery, but not a single miller in Maryland, Pennsylvania, Delaware or Virginia would have anything to do with "such rattle traps." This was most disheartening to Evans for it meant delay in taking up steam-wagon experiments, but for the next year or two, while his brothers ran the mill, Evans continued pestering millers to buy his equipment, and was finally rewarded with one order from the Ellicotts in Maryland, whose mills were located in what is now Ellicott City.

Taking his share of the profits from this installation, Evans moved to Philadelphia about 1790, and for the succeeding 10 years or more lived a hand-to-mouth existence, selling an occasional bit of flour-mill machinery and supplies. He even wrote a book called the

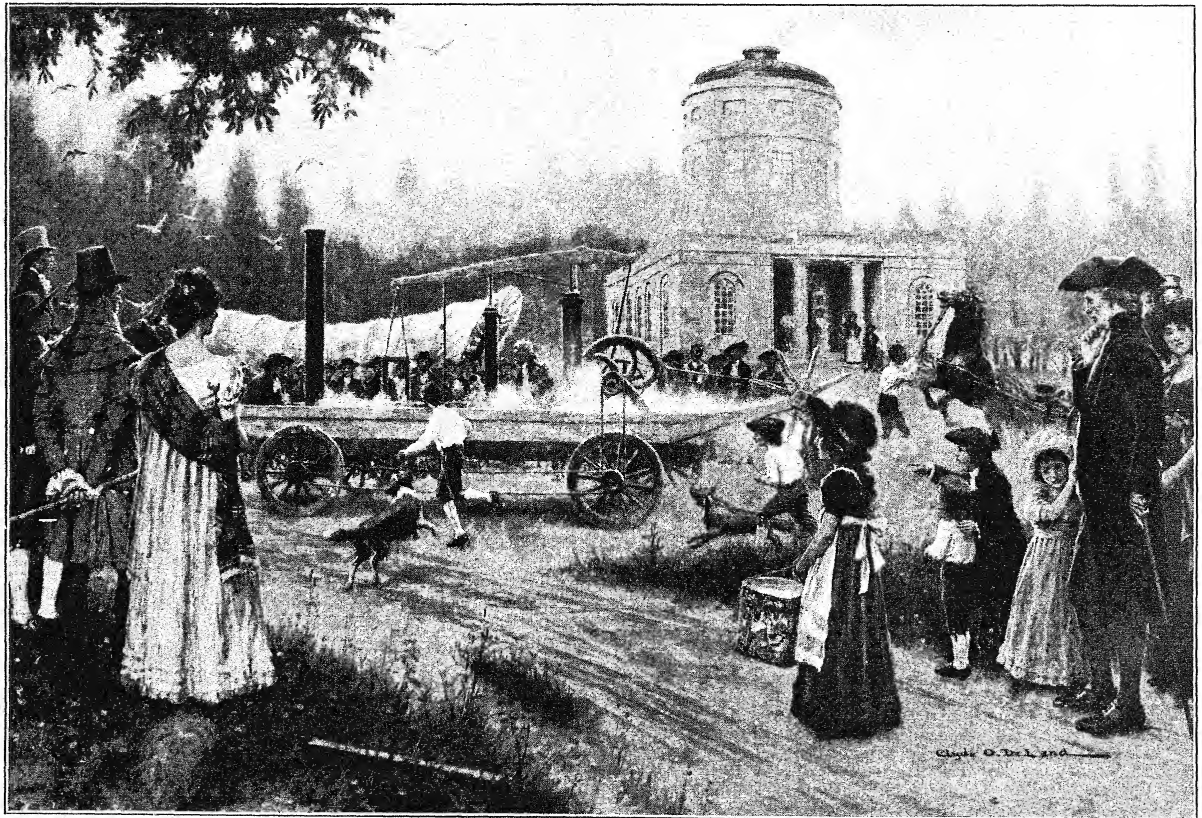
"Millwright and Miller's Guide," but its sales did not cover the cost of publication. All this time, too, he tried, but without success, to induce someone to advance him the necessary capital to build an experimental traction engine. In 1801, poor as he was, he began work using his own limited funds.

Before the engine was completed Evans concluded that as its principle (a high-pressure type) differed from any of those then in use, it might be worth while to make some other application of it than to a tractor. So he began on a small stationary steam engine, and had it running in the winter of 1801. With it he ground plaster of Paris, then used as a fertilizer, grinding 12 tons in 24 hours. He also used it to saw marble. To build it had cost him $3,700 but he got the money back very shortly when he received an order for an engine to be used to drive a steamboat on the Mississippi River at New Orleans. Evans delivered the engine in due time. While awaiting installation in the boat it was used to saw lumber. It ran thus for a year without failure, when an incendiary fire, believed to have been the work of hand sawyers whose business had been injured by the engine, destroyed the lumber mill. Ten years later, however, the engine was reconditioned and used to drive a cotton press. It never served the original purpose for which it was purchased.

As things were now looking brighter for Evans, he opened up a shop in Philadelphia, as a regular engine builder, and was probably the first in the United States to make a specialty of this work. One of his first big jobs was an order from the Philadelphia Board of Health for the building of a steam dredge to clean the docks of the city. He completed it about July, 1805, and as his shop was a mile and a half from the Schuylkill River where the dredge was to be launched, Evans put wheels under the scow, and by means of a series of belts between the engine and wheels, transported it under its own power to the river. Evans called the dredge *Oruktor Amphibolos*, or amphibious digger. Before launching it he drove the machine around Center Square during several days, and, through advertisements in the daily papers, invited anyone to visit the square and inspect the machine. He charged each visitor 25 cents, one-half of which he applied to his inventive work and the other half gave to his men. This was the first steam-operated vehicle in the United States.

Two years later Evans established the Mars Works, announcing himself as an iron founder and steam engineer, and directed it until his sudden death in 1819, at which time at least 50 of his engines were in use in many eastern States. Death, however, robbed him of the realization of his most cherished ambition.

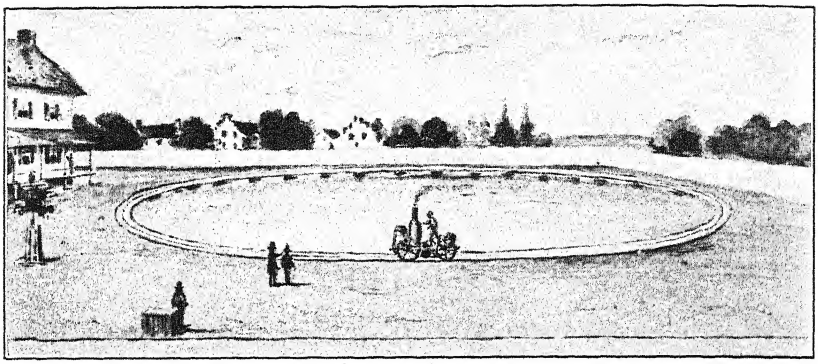
The most logical field for a road locomotive in Evans's day was in hauling freight to Pittsburgh. To haul 100 barrels of flour from



Courtesy of artist and the Continental Insurance Co.

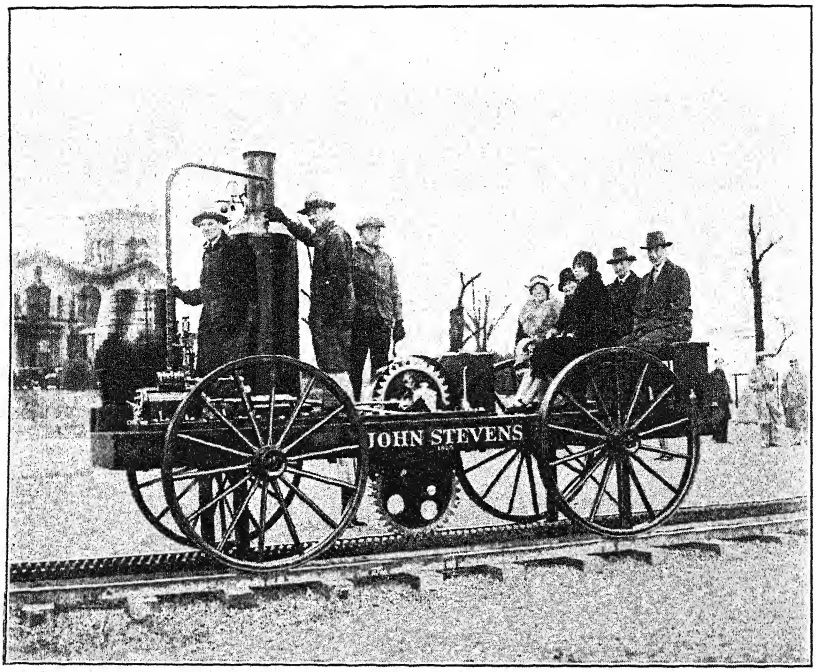
EVANS'S STEAM-PROPELLED DREDGE, 1805

The "Oruktor Amphibolus" as it was called, was the first self-propelled vehicle in America. (From a painting by Clyde O. Deland.)



1. STEVENS'S LOCOMOTIVE DEMONSTRATION, 1825

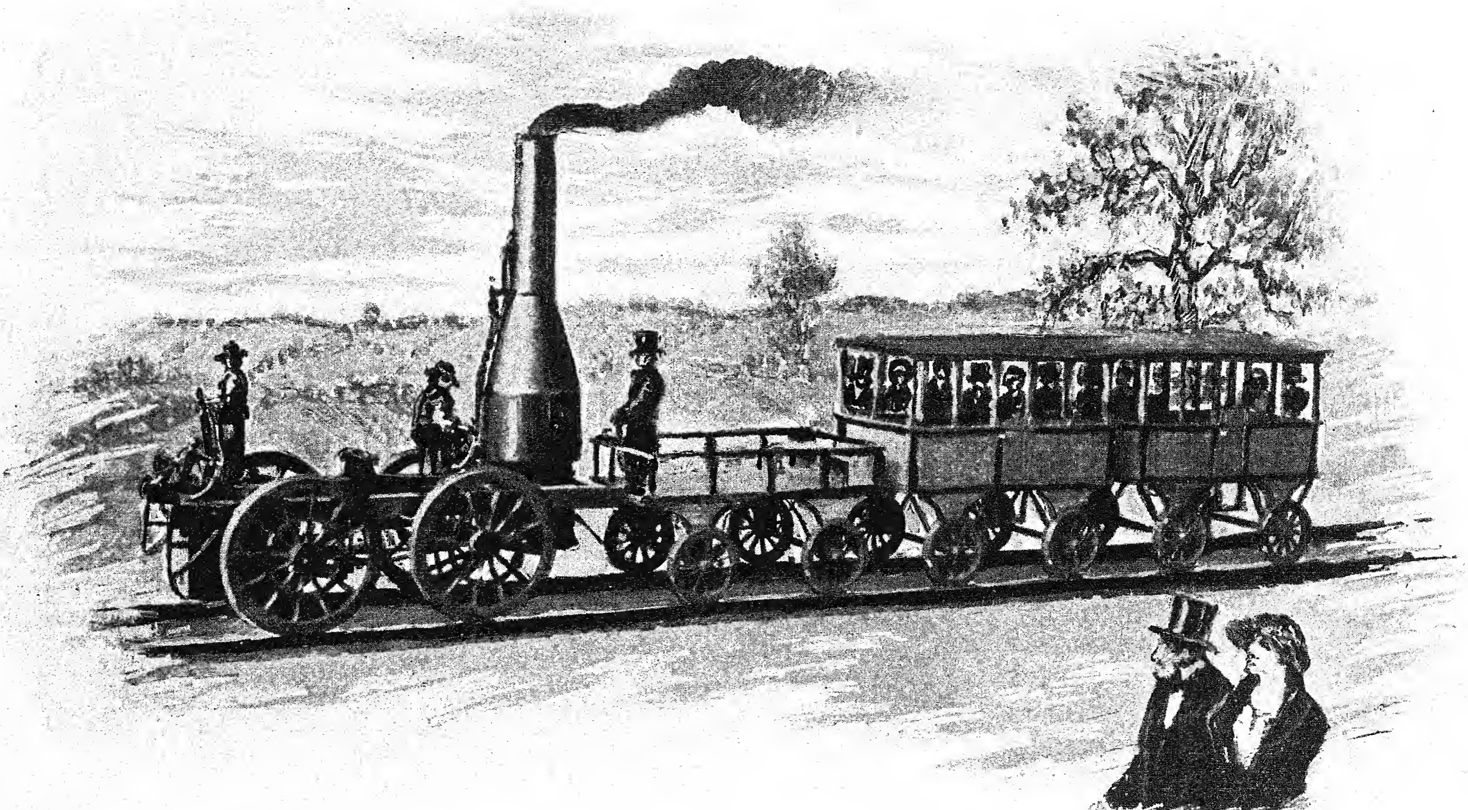
To prove that steam locomotion was feasible, Stevens built an experimental locomotive and operated it on a circular track laid on the lower lawn of his estate, Castle Point, Hoboken, N. J.



Courtesy of Stevens Institute of Technology

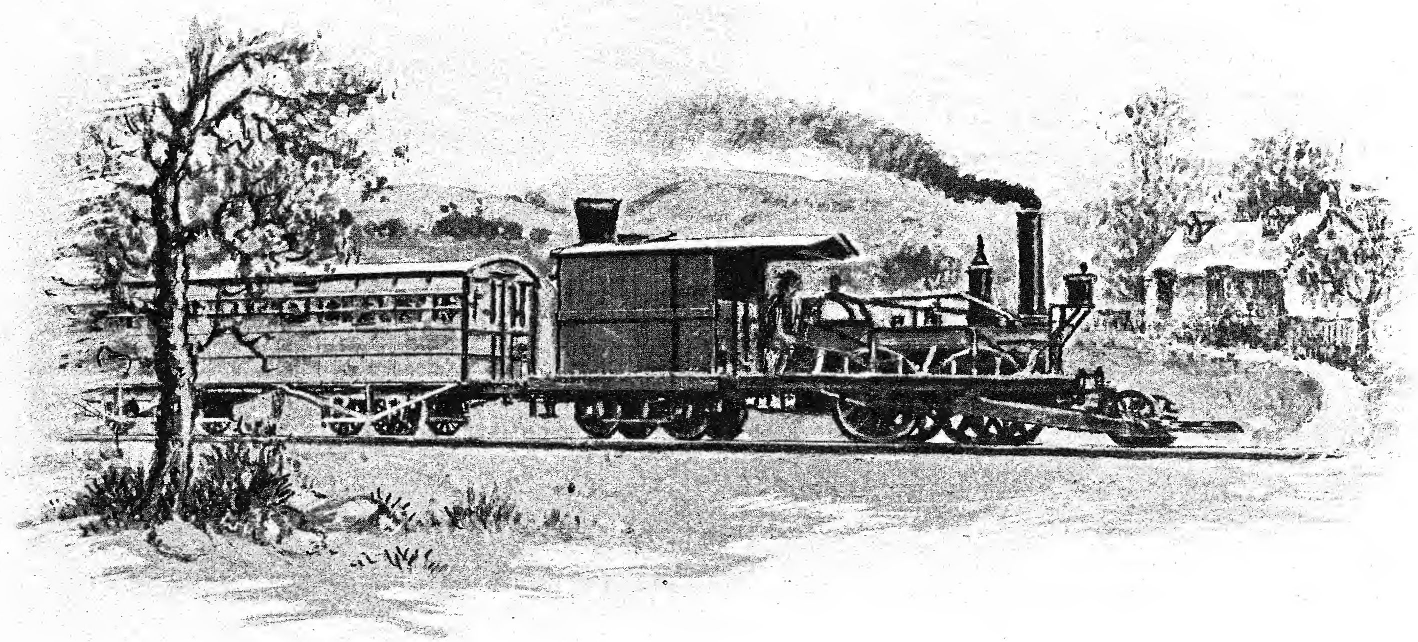
2. REPRODUCTION OF STEVENS'S LOCOMOTIVE

This operative copy was built by the Pennsylvania Railroad Co. in 1928 and run over a circular track laid on the Athletic field of Stevens Institute, Hoboken, N. J.



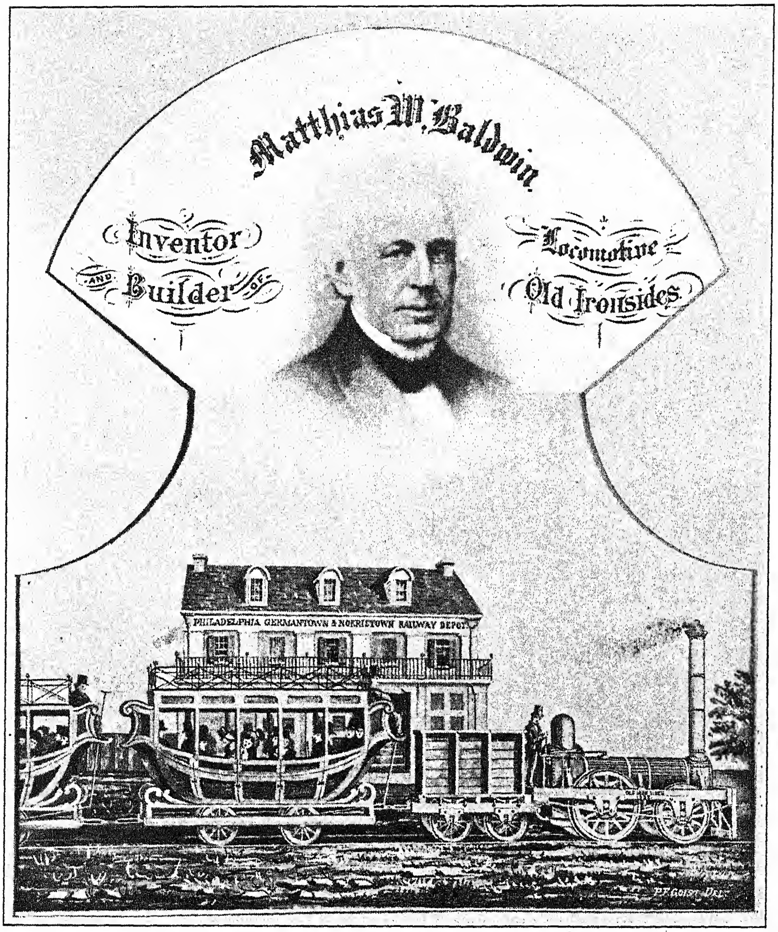
LOCOMOTIVE "BEST FRIEND" AND TRAIN ON THE CHARLESTON & HAMBURG RAILROAD, 1830

The first locomotive designed and built in America for service on a railroad. Constructed by the West Point Foundry, New York City.



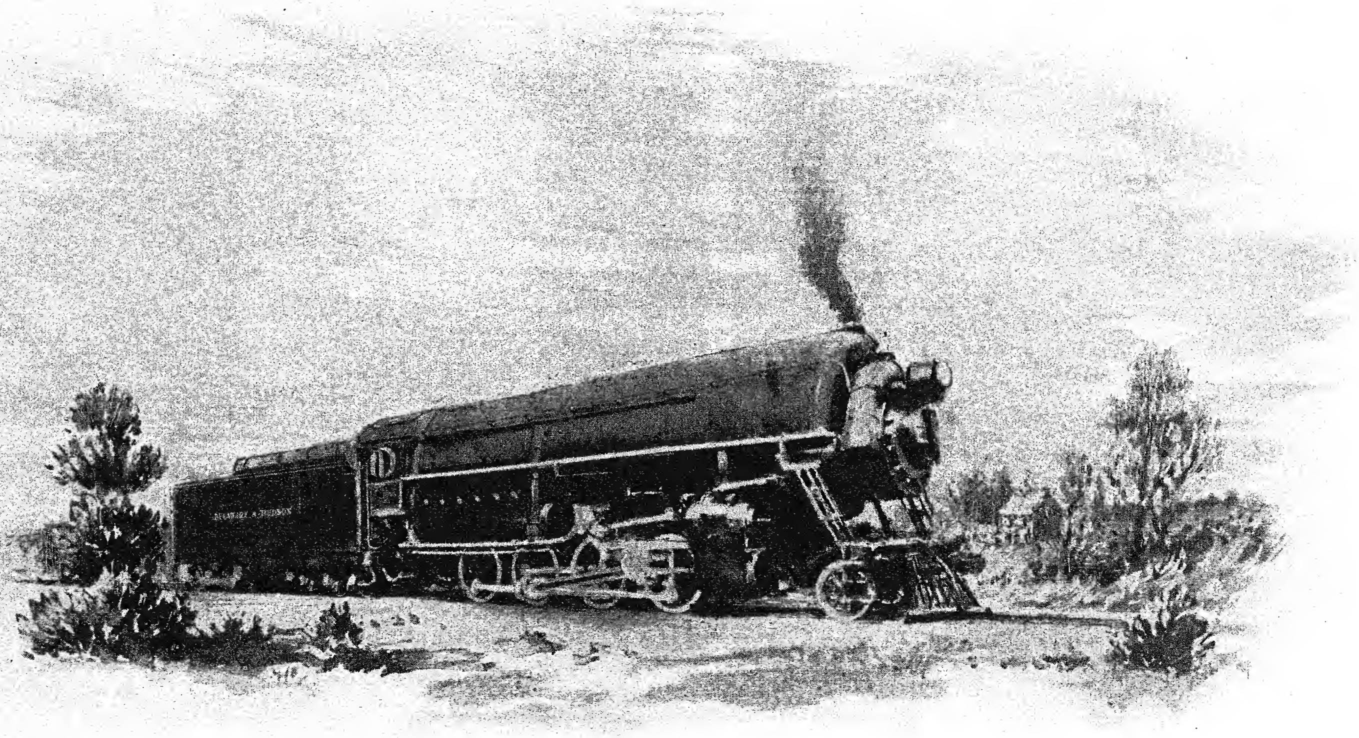
LOCOMOTIVE "JOHN BULL" AND TRAIN ON THE CAMDEN & AMBOY RAILROAD, 1831

Built by Stephenson in England for the first railroad in the State of New Jersey. Weight, 10 tons. This engine is now in the National Museum and is the oldest complete locomotive in America.



MATTHIAS W. BALDWIN, 1814–1866

Builder of the first successful American-built locomotive in Pennsylvania, "Old Ironsides," 1832, and founder of the Baldwin Locomotive Works, Philadelphia, Pa.



Courtesy of the Delaware & Hudson Railroad Co.

LOCOMOTIVE "JOHN B. JERVIS, NO. 1401," ON THE DELAWARE & HUDSON RAILROAD, 1927

Built by the American Locomotive Co. from designs of the D. & H. Railroad Co. for freight service. This locomotive and tender weigh over 300 times more than the "John Bull" of 1831.

Philadelphia to Columbia, on the Susquehanna River, required five of the customary Conestoga wagons with five horses each and 73 hours' time. Evans proposed at one time to one of the freighting companies to do the same thing with one traction engine in 48 hours. But no one in that company or any other paid the slightest attention to him. In his disappointment he wrote in 1812 an Address to the People of the United States in which appeared the following: "The time will come when people will travel in stages moved by steam engines from one city to another almost as fast as birds fly, 15 to 20 miles an hour. Passing through the air with such velocity changing the scenes in such rapid succession will be the most exhilarating, delightful exercise. A carriage will set out from Washington in the morning and the passengers will breakfast at Baltimore, dine at Philadelphia, and sup at New York the same day.

"To accomplish this, two sets of railways will be laid * * * made of wood or iron, on smooth paths of broken stone or gravel with a rail to guide the carriages so that they may pass each other in different directions and travel by night as well as by day; and the passengers will sleep in these stages as comfortably as they do now in steam stage boats. * * * and it will come to pass that the memory of those sordid and wicked wretches who oppose such improvements will be execrated by every good man, as they ought to be now."

Whether Evans would have been successful with his road engine no one can say, but one can not help but admire his determination, as well as the courage with which he expressed his convictions.

Stevens outlived Evans almost 20 years, but Evans's death brought to a close the first period of American invention in steam. Fitch, the surveyor, Rumsey, the millwright, and Stevens, the lawyer-engineer, deliberately chose one of the most difficult problems in steam-power application. They knew, however, that better transportation was the greatest need of the colonies at that time and devoted their lives in an effort to bring that about. For their efforts and sacrifices the nation owes them much honor. Evans chose to experiment with locomotion on land, but, failing in this, founded America's stationary steam engine industry and pointed the way for the industrial use of steam power. He did much to allay the fears of high-pressure steam and gave to the milling industry, in principle, the system of mechanically handling grain and flour. "Wherever the steam mill resounds with the hum of industry, whether grinding flour on * * * the Schuylkill, or cutting logs in Oregon, there you find a monument to the memory of Oliver Evans."

JOHN STEVENS

John Stevens eventually had better luck in his fight for railroads than did Evans. When he heard in 1811 that the commission ap-

pointed by the New York State Legislature to study and recommend a method to improve the existing overland transportation system had suggested the building of the Erie Canal, he denounced the plan vigorously in a printed pamphlet and strongly urged a railroad. He did not then make much of an impression, however, especially as the canal recommendation had come from three such prominent men as De Witt Clinton, Gouverneur Morris, and his own brother-in-law, Robert Livingston. In 1812 he followed his pamphlet with a similar proposal to Congress but with no better results. In 1815, when New Jersey gave him authority to build a railroad to connect New York and Philadelphia, he could not get the necessary financial help to construct it. Refusing to be discouraged, Stevens turned to Pennsylvania and succeeded in convincing Horace Binney and Stephen Girard, two prominent Philadelphians, of the feasibility of railroads. In 1819 the three petitioned the Pennsylvania Legislature for a railroad charter for a road between Philadelphia and Pittsburgh. This was granted four years later, but for a State-owned road between Philadelphia and Columbia. The three incorporators, however, did not possess the $600,000 estimated as necessary to build it, nor could they entice any money from anyone else. Their continual conversations and discussions about railroads had another effect, however, in that it brought about in 1824 the organization in Philadelphia of the Pennsylvania Society for the Promotion of Internal Improvements in the Commonwealth. This society immediately dispatched William Strickland, a civil engineer, to England to study and report on railways and locomotives. The encouraging fact in this move, especially to Stevens, was that Strickland had instructions to find out how railroads and locomotives were built, not whether they were of any value, showing that the idea of railroads had begun to take root.

Stevens next sought to stir up public interest and activity in behalf of railroads. The placid acceptance of the pack horse and stagecoach grated on him, and his exasperation knew no bounds when he read in newspapers such statements as this: "I see what will be the effect of it; that it will set the whole world a-gadding. Twenty miles an hour, sir! Why, you will not be able to keep an apprentice boy at his work! Every Saturday evening he must have a trip to Ohio to spend a Sunday with his sweetheart. It will encourage flightiness of intellect. All conceptions will be exaggerated by the magnificent notions of distance. Only a hundred miles off! Tut, nonsense, I'll step across, madam, and bring you your fan." As a step in practical advertising, Stevens in 1825, when he was 76 years old, designed a steam locomotive and operated it on a circular track on his estate at Hoboken. Of course the number of people who actually saw this first locomotive was limited, but these were enthusiastic, and their account as well as the newspaper stories of the demonstrations had a

very beneficial effect in modifying the antagonistic attitude toward steam transportation.

Compared to modern locomotives Stevens's was indeed queer looking. Instead of being propelled by the tractive force of the driving wheels, as is the method to-day, this first locomotive was moved by means of a large gear wheel engaging a toothed rack placed on the ties between the rails; and to keep it from running off the track—for the wheels had no flanges—little horizontal friction rollers fixed to posts like table legs on the underside of the chassis pressed and rolled along the inner vertical face of the wooden beams used for rails. Steam for the small horizontal engine was generated in an upright multitubular boiler, also designed by Stevens. This part is all that remains of America's first locomotive and is now to be seen in the National Museum.

Stevens hoped that his locomotive might be used on the proposed State-owned Philadelphia & Columbia Railroad, but legislators had not fully made up their minds that a boiler and engine on wheels were a good substitute for horses. When, however, Strickland came back from England later on in that same year and submitted his wonderful pictorial report of railroad and locomotive activities over there, railroad opposition began to totter and a new age in America opened. On April 4, 1827, the Delaware & Hudson Co. directed its chief engineer to survey and locate a railroad route to connect its canal and coal mines; on April 24, 1827, the Baltimore & Ohio Railroad Co. came into existence; and the Charleston & Hamburg Canal & Railroad Co. was formed May 12, 1828, at Charleston, S. C. The Delaware & Hudson Co. sent Horatio Allen to England on January 24, 1828, to purchase rails and four locomotives. The first of these, the Stourbridge Lion, arrived in New York May 13, 1829, but after two trials, the first on August 8, 1829, on a 6-mile track out of Honesdale, it was set aside and never used again. Sixty years later its boiler, one cylinder, and the four iron wheel tires, all that remained of the locomotive which made the first run on a railroad built for traffic in the Western Hemisphere, were deposited in the National Museum. Finally and before 1830 rolled around, Peter Cooper, in order to demonstrate the feasibility of steam locomotives to the stockholders of the Baltimore & Ohio Co., built and successfully operated a little locomotive on the company's tracks outside of Baltimore. The engine, called Tom Thumb, for it was no bigger than a hand car, and Cooper himself, had but one embarassing moment. That came when a horse and car beat Tom Thumb and car in a 13-mile race from Ellicott City to Baltimore.

The organization of the Camden & Amboy Railroad on April 28, 1830, five years after he had received the State rights, must have given great satisfaction to John Stevens. This was the first railroad in the State of New Jersey and the first link in the Pennsylvania Railroad chain.

Two of the company's first officers, the president and treasurer, were Stevens's own sons, Robert and Edwin. By October, 1830, Robert was on his way to England to order a locomotive and iron rails, and about a year later, on November 12, 1831, the locomotive John Bull was put into service at Bordentown, N. J. After something over 50 years of service the John Bull was retired with fitting ceremonies. Since then it has rested in the National Museum, honored as the oldest complete locomotive in America.

For a few years following the organization of the first railroad companies, the chief topic for discussion in their meetings was the question of motive power. Stockholders were by no means as thoroughly convinced that steam power ought to be used as were Stevens and Cooper. Horse-drawn cars were employed and also horse-power treadmill cars. A horse treadmill car hauling 24 passengers won a $500 prize offered by the stockholders of the Charleston & Hamburg Railroad in 1829. Cars equipped with a mast and sail were tried on both the Charleston & Hamburg and the Baltimore & Ohio. But when the news came from England in 1829 of the wonderful performances of George Stephenson's steam locomotive Rocket, all doubts as to this new motive agent were soon removed. The steam train came into its own.

Shortly after this time Robert Stevens forestalled a possible loss of this new confidence, which the inevitable failure of wooden rails might have brought on, when he perfected, had rolled in England, and introduced in America the iron rail. Adopting the T-rail then popular in England, he added the base and produced a rail that has remained almost unchanged in design to this day. He also designed the hook-headed spike, which is substantially the railroad spike of to-day; the iron tongue which has been developed into the modern fish plate; and the bolt and nuts to complete the joint. These improvements laid the essential ground work on which to build the new industry sucessfully.

LOCOMOTIVES

Who was to build the locomotives? That question had to be answered at once. Several of the wealthier companies had purchased locomotives in England but the cost of this was prohibitive. What the United States had at that time in the way of machine shops were principally forges, wheel, and millwright shops. In the large cities, so-called foundries did all sorts of jobbing in metals, while other shops specialized in machinery repair work, mostly of steamboat engines. Of these the most prominent in 1830 was the West Point Foundry in New York, and to this concern the railroad pioneers naturally turned. Out of this shop came the first American-built locomotives—the Best Friend and West Point, used on the Charleston

& Hamburg Railroad in 1830 and 1831, respectively, and the Dewitt Clinton, sucessfully operated on the Mohawk & Hudson Railroad, the forerunner of the New York Central system, in 1831. The foundry owners, however, did not regard locomotive building as a very promising business, and after completing two or three additional engines, declined further orders.

Meanwhile, as agitation in favor of railroad building intensified, small machine shop owners, watchmakers, and even a United States topographical engineer all dabbled in locomotive construction. Their first big chance to show what they could do came in 1831 when the Baltimore & Ohio offered a premium of $4,000 for a locomotive that would pull 15 tons at a speed of 15 miles an hour. Five would-be locomotive builders entered the competition: Johnson, a machinist of Baltimore, in whose shop Peter Cooper assembled the Tom Thumb; James, a mechanical genius of New York, who is said to have invented the link motion for locomotives; Davis and Gardner, a watchmaker-machinist combination of York, Pa.; Costell, a watchmaker of Philadelphia; and Childs, also a watchmaker of Philadelphia. Davis and Gardner won with their locomotive York, and Davis became manager of the Baltimore & Ohio shops shortly afterwards. Three years later he was killed, when one of his locomotives overturned while on a trial run from Washington to Baltimore. Of Costell, Childs, and Johnson, nothing further was heard after their first venture.

Besides these somewhat casual experimentalists there were others who organized shops specifically for locomotive building. Many soon passed out of the picture, but a sound beginning toward an American locomotive works was made when Col. Stephen Long of the United States Corps of Topographical Engineers and Jonathan Knight, first chief engineer of the Baltimore & Ohio Railroad, obtained a charter in 1830 from Pennsylvania for the American Steam Carriage Co. When Long's locomotive proved a dismal failure this company came to a premature end, but it was resuscitated two years later as Long & Norris, and operated successfully for many years. In fact it was the admirable performance of Norris's locomotives in England and on the Continent in the 1850's that first established an international reputation for American locomotives generally.

MATTHIAS W. BALDWIN

Matthias W. Baldwin, the founder of the Baldwin Locomotive Works at Philadelphia, was also drawn into the locomotive industry in this period and in a rather unusual way. Though he had been a jeweler and silversmith by trade from the age of 16, in 1830 he formed a partnership with a machinist for manufacturing bookbinder's tools and calico printing cylinders. For the firm's use Baldwin had built a steam engine which was both unique in design and most efficient for

its day, and which had attracted quite a lot of attention, especially from other manufacturers in Philadelphia. This might have constituted his sole achievement in steam engineering had it not been for Franklin Peale, the proprietor of the Philadelphia Museum. Peale wanted a working model of a locomotive and train to exhibit in the museum. He knew of the admirable work that Baldwin had done with his steam engine, and after much pleading succeeded in getting the latter's promise to make the model for him. Baldwin's acquaintance with locomotives was limited to pictures and descriptions of Stephenson's Rocket and other English locomotives. He obtained permission to examine the various parts of the John Bull, which had arrived unassembled at Bordentown, N. J. Armed with these data he set to work and had the model operating under its own steam on April 25, 1831.

Again Baldwin returned to the making of tools for bookbinding, but within a short while he was requested to build a full-sized locomotive, this time by the officers of the newly organized Philadelphia, Germantown & Norristown Railroad Co. They had seen his model in the museum and were so pleased with it that they were determined to have Baldwin build a full-sized machine for them. He had an anxious time with this attempt, however, due mainly to the lack of proper equipment and tools. For instance, to bore the steam cylinders all he had was a chisel fixed in a block of wood and turned by hand. Blacksmiths able to weld iron bars over 1¼ inches in thickness were rare. Baldwin stuck to it, however, and Old Ironsides was tried out on November 23, 1832. After three days' trial it was put in regular service on the railroad and continued in use for over 10 years. The railroad officials were greatly pleased with this new accession, treated it most tenderly and kept it home on rainy days. Their first newspaper advertisements giving the train schedules stated that the locomotive "will depart daily when the weather is fair" but that "the cars drawn by horses will depart when the weather is not fair." Baldwin, on the other hand, had had enough of locomotives and remarked to one of his friends, "This is our last locomotive."

It looked as if there would be as much diversity in design of locomotives in America as there had been in marine engines up to that time. No American locomotive had set the fashion as Stephenson's Rocket had in England and Europe generally. All five locomotives entered in the Baltimore & Ohio Railroad competition had scarcely one point of resemblance among them. Cooper's Tom Thumb had an upright boiler, as did the Best Friend, but the boiler on the West Point was horizontal. Old Ironsides was a four-wheeled engine, had a horizontal boiler, and was modeled essentially on the English practice of that day, but the South Carolina, designed by Horatio Allen, chief engineer of the Charleston & Hamburg road, was a kind of Siamese twin, with two horizontal boilers joined stern to stern.

In the midst of this confusion Baldwin undertook his second locomotive. In spite of his intentions to stay away from locomotives, the subject fascinated him so much that when E. L. Miller came to him with an order to build a locomotive for the Charleston & Hamburg Railroad, he accepted immediately. In the period between the completion of Old Ironsides and the receipt of this order Baldwin had spent a good deal of time and thought on locomotives, and had examined another English engine, the Robert Fulton, placed on the Mohawk & Hudson Railroad in 1832.

He was particularly impressed with the alteration made on this locomotive by John B. Jervis, chief engineer of the Mohawk, in the substitution of a four-wheeled swiveling truck for the original two front wheels. So, when the opportunity came to build another locomotive Baldwin adopted this design. He also incorporated some improvements of his own, such as the half crank. But in the main he simply combined old forms in a shape that produced the best locomotive then built. It had a boiler that anyone could understand and that any boilermaker could repair, a valve motion which was not a mystery, a running gear of combined strength and simplicity, and a pair of cylinders firmly attached between smoke box and frame. Simplicity was his prime object and with the completion of the E. L. Miller as it was called, on February 18, 1834, a national type of locomotive was established from which the American locomotive of to-day has come.

Thereafter Baldwin remained in the locomotive business, spending his time in perfecting improvements not only in engine design, but also in manufacturing methods. At the time of his death in 1866 his company had built over a thousand locomotives, and there was left to his successors one of the greatest industrial establishments ever built by the genius and enterprise of one man.

TRAIN BRAKES AND COUPLERS

The first five years of the railroad era saw an increase in tracks laid from 23 miles in 1830 to over 1,000 in 1835. To build locomotives and passenger and freight cars to keep pace with such leaps was no easy task. So intent were the builders on turning out satisfactory engines—locomotives that could be depended on to move and pull the cars—that little or no attention was paid to the problem of stopping them.

This minor matter was left in the beginning to the ingenuity of crews. Some of the schemes devised were ludicrous enough. On one or two of the railroads, as a train approached a stopping point the fireman opened the safety valve and the hiss of the escaping steam (the whistle had not yet been invented) warned everybody at the station to stand by. The engineer closed the throttle and coasted

sometimes as far as a half mile from the station. As the locomotive and cars drew up to the waiting platform all hands there took hold, dug their heels in the ground and held on till a dead stop resulted. An adaptation of the ordinary wagon brake with wooden brake shoes followed soon after, and a brakeman was added to the crew, who when the time came for brakes, dropped a horizontal lever out of its notch at the end of a car and stood on it. This scheme worked fairly well until locomotive builders, in response to the demand of industrialists for faster freight service, designed speedier machines, capable of running not 15 but 30 and sometimes 40 miles an hour. About this time, too, four-wheeled car trucks came into use and the combination of speed and additional wheels was just too much for the old lever brake. By a number of stages it was replaced by a hand wheel to operate iron shoe brakes applied to both trucks of a car. If cars were properly coupled, a brakeman could work two adjoining cars by simply stepping from one platform to the other. This was so far ahead of all previous devices that the railroads spent thousands of dollars to equip their rolling stock, hoping thereby to reduce the number of train wrecks, both of freight and passenger trains, which were increasing at an appalling rate.

It is a matter of regrettable history that the man who invented this new braking system, Willard J. Nichols, never received a penny of reward. He was a car-shop foreman on the Hartford & New Haven, now part of the New York, New Haven & Hartford Railroad. Like many other railroad men he had been trying for years to devise some better form of brake, and when he finally perfected his idea he applied it to some of the cars of his employer. He did not patent his product so that others appropriated its valuable features, and obtained patents in their own names. To them went the money paid by the railroads.

This was the type of brake generally used in the fifties and sixties. With one brakeman to each two cars a train could be brought to a stop from a running speed in about half a mile. But, as traffic on the prevailing single-track roads became more congested, many were the collisions, accompanied in many instances with large losses of life and property. The public naturally blamed the railroads. The railroads, in turn, pinned the responsibility partly on the brakes, and were about convinced that nothing in the way of a real improvement could be devised, when a young New York State Yankee came forth with his air brake system.

GEORGE WESTINGHOUSE

George Westinghouse was born October 6, 1846, in Central Bridge, N. Y., a little village not very far from Schenectady. His father although born and bred a farmer, was at that time engaged in a small way in manufacturing a thrashing machine containing improvements of his own invention, as well as his patented winnowing machine and

endless chain horsepower. He prospered in this undertaking and when George was 10 years old he transferred the business to Schenectady, where better facilities were to be had. From all accounts George much preferred playing with the gang or tinkering in his father's plant to going to school. His father, in an endeavor to direct his interests in some definite channel, offered to pay him for any of his time spent in the plant, provided it was devoted to some specific undertaking having to do with the business, but this had no appeal. If he was going in the shop at all, he wanted freedom to work on his own conceptions—mostly mechanical toys—and that is usually what he did.

At 17 George enlisted for the balance of the Civil War, first in the Army, and then in the Navy as an acting third assistant engineer. He returned home in the summer of 1865, and that autumn entered the sophomore class of Union College at Schenectady, chiefly because it was his father's wish. But he could not get interested in the classics or languages, his whole concern being with things mechanical. After a 3-months' trial, both his father and the college president decided there was no use insisting any longer on a college career for George, and he went to work for his father.

While making a business trip he observed the laborious way in which derailed railroad cars were put back on the track. Obviously there existed a market for a device to replace cars more expeditiously. Within a short time he had patented his car replacer. When his father refused to engage in its manufacture because it was foreign to his line of work, George interested two Schenectady men in it. A partnership was formed with Westinghouse as salesman. Manufacturers in Troy, New York City, and Pompton, N. J., were engaged to manufacture the replacer as well as a new railroad frog Westinghouse had invented, and for a year or more he traveled about selling these devices. On one of his trips in 1867, he was an eyewitness of a head-on collision of freight trains, and that led him to experiment with brake mechanisms.

Many American and European inventors were working on this very problem; all sorts of schemes had been patented and some tried. One idea common to all was to obtain continuous braking action, controlled, if possible, by the engineer. Westinghouse thought a long chain running the full length of the train, to which all the brakes were connected, might do. He was surprised, however, to find that such a system was just then to be tried on one of the large railroads out of Chicago. In this, a windlass on the locomotive turned by a grooved wheel engaging the flange of one of the drivers, wound up the chain. The inventor of this system explained everything to young Westinghouse, and when the latter dropped a hint that he was thinking of a braking scheme, he was told, "You are throwing away your time,

young man. I went all over the ground before completing my invention, and my patents are broad enough to cover everything." This did not deter Westinghouse, however. It seemed to him that to draw the chain taut by a steam engine piston would be better than a windlass, but he quickly realized that a locomotive with room for a cylinder and piston large enough to take up the chain slack of a 20-car train did not exist. Like other inventors working on the same problem, he considered individual steam cylinders for the brake gearing of each car, only to discard the plan as unfeasible. He could not help feeling, however, that the idea of each car having its own brake-actuating mechanism was the correct one, if only some other form of energy than man or steam power could be found. He did find it in a most unexpected way.

To help a young lady through normal school he had subscribed to a magazine called "The Living Age." The first number he received contained an account of the boring of the Mount Cenis Tunnel through the Alps, and told of the use of rock drills operated by compressed air. What caught Westinghouse's attention was the fact that the air was transmitted through pipes a distance of 3,000 feet without any appreciable loss in effectiveness, and he knew then that compressed air was the energy he should use for his brake.

From this time on things moved rapidly. Every waking moment was given to working out the air-brake system. The desertion of his car-replacer partners forced him to go to Pittsburgh to find another manufacturer. When he found one who would make the replacer, and take him on as a salesman, he filed a caveat on his air-brake system with the Patent Office in Washington. After that, in discussion with railroad men about the car replacer, he also talked air brake. It was an uphill fight lasting a good many months. He had no money to speak of so that he had to find some one to subsidize the manufacture of one outfit in order that he might equip a train and give a demonstration. After many vicissitudes, including the paying of a hundred dollars to have an expert tell him his invention was good for nothing, the superintendent of the division of the Panhandle Railroad extending from Pittsburgh to Steubenville, Ohio, agreed to give the brake a trial and he found a manufacturer in Pittsburgh who would make the equipment.

A locomotive and four passenger cars were fitted up soon afterward, and one day in September, 1868, the train pulled out of the Pittsburgh station, the cars filled with invited guests. It got under way quickly and was speeding along at 30 miles an hour when suddenly every one heard the grating sound of the brakes, suffered a violent jar, and the train stopped. Rubbing their shins and pushing dents out of their hats, the passengers limped out of the cars in time to see that the cow-catcher of the engine was just about 4 feet away from a man

sprawled between the tracks, and the engineer in the act of helping the man to his feet, unhurt. Westinghouse could not have hoped for a more convincing demonstration than this, and was elated. After a subsequent demonstration made with a Pennsylvania Railroad train, which traveled all over the East and Middle West, Westinghouse was granted his first patent of the air brake on April 13, 1869. Shortly thereafter he organized a company in Pittsburgh and began the manufacture of his brake.

Soon on many trains compressed air did the work of the brakeman's muscles, the air flowing through a pipe from a tank on the locomotive, going to a little cylinder on each car, and moving a piston in and out to apply or release the brakes. Troubles developed, however. The brakes on the last cars of a train did not work as soon as those nearer the locomotive because it took longer for the air to reach them; and again, when the air pipe line was accidently uncoupled, the air supply to all of the cars back of the uncoupled point was cut off and the brakes would not operate at all. Westinghouse corrected all of this with his clever invention of the "triple valve" which he patented March 5, 1872. With this little device, and an air tank added to each car, Westinghouse made the little cylinder and piston apply the brakes when the air supply from the locomotive was cut off. No matter how it happened—whether the engineer reduced the air intentionally, or there was an air leak in the pipe line, or cars broke apart—the instant the air pressure was reduced the brakes were applied on every car. A 10-car passenger train could now be stopped when going at a speed of 20 miles an hour in 166 feet, whereas the same train with hand brakes required 764 feet.

This was so much better than the straight air brake which Westinghouse first perfected that it was not long before passenger trains were all equipped. Not so with freight trains, however. They were of much greater length and of very much greater rolling weight, and it was 15 years after the "triple valve" was invented before the automatic air brake was generally recommended and adopted for freight cars. This came about only after Westinghouse with his improved automatic air brake, still with the triple valve, succeeded in applying the brakes throughout a 50-car train in two seconds. This same system, improved in detail to take care of the modern heavy locomotive and rolling stock, is in use to-day.

Westinghouse had passed 40 when the air brake was finally adopted for all railroads. He had devoted fully 20 years of his life to bring this about, perfecting and patenting many of the improvements himself. The Patent Office model of one of these, made in 1879, forms an interesting part of the railway collections in the National Museum. About 1890 he added electric-power equipment manufacture to the activities of his well-established organization, and in the succeeding

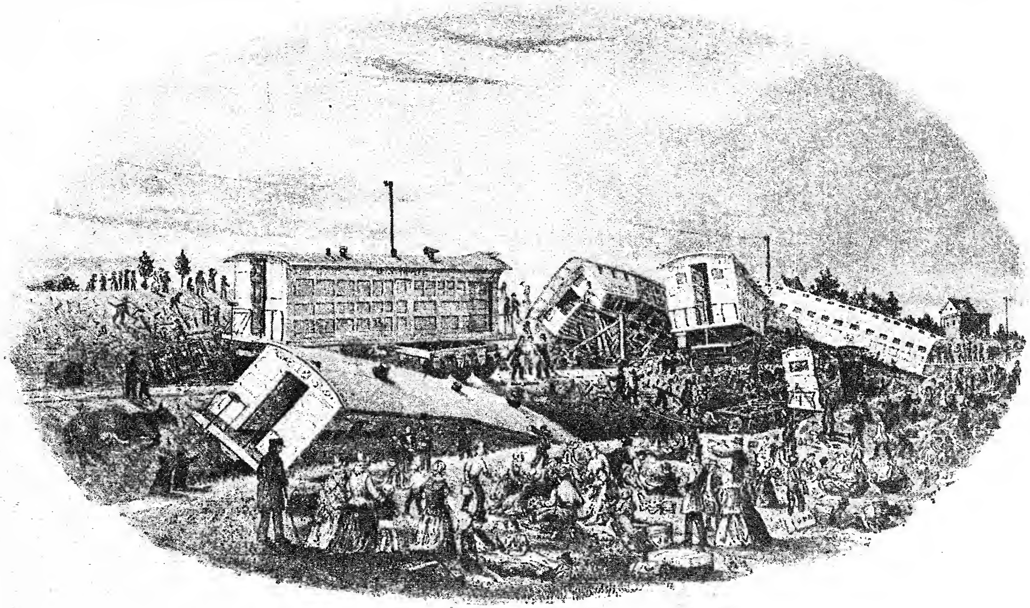
25 years up to his death in 1914, built up the great Westinghouse enterprise still prominently identified with the electrical industry.

The perfection of the air brake removed one great source of danger that menaced railroad travelers as well as train crews, but there still remained another, that of coupling cars in a train. The first cars used on the railroads were simply stagecoaches equipped with flanged wheels and coupled together with a kind of hook-and-eye arrangement. These were followed by regularly designed cars with heavy wooden crosspieces at each end to serve as bumpers and to hold the coupling arrangement. In later developments some form of cross member to serve as a bumper was retained, but instead of hooking cars together at these crosspieces, a long iron bar called a drawbar was devised and secured to the under side of the car some distance back of the ends. The free end of this drawbar was split in two horizontally, and a hole bored vertically through the two halves. To couple cars there were provided heavy iron links about a foot long and iron pins, and it was the job of the brakeman as cars came together to guide the link into the split end of the drawbar, and then drop the pin down the hole in the latter to hold the link. The clearance between cars was not great, and almost daily came reports of the injury or death of brakemen in doing this work. The years saw the development of a great variety of automatic coupling mechanisms, all of which gave way when all railroads adopted that of Janney in principle.

ELI H. JANNEY

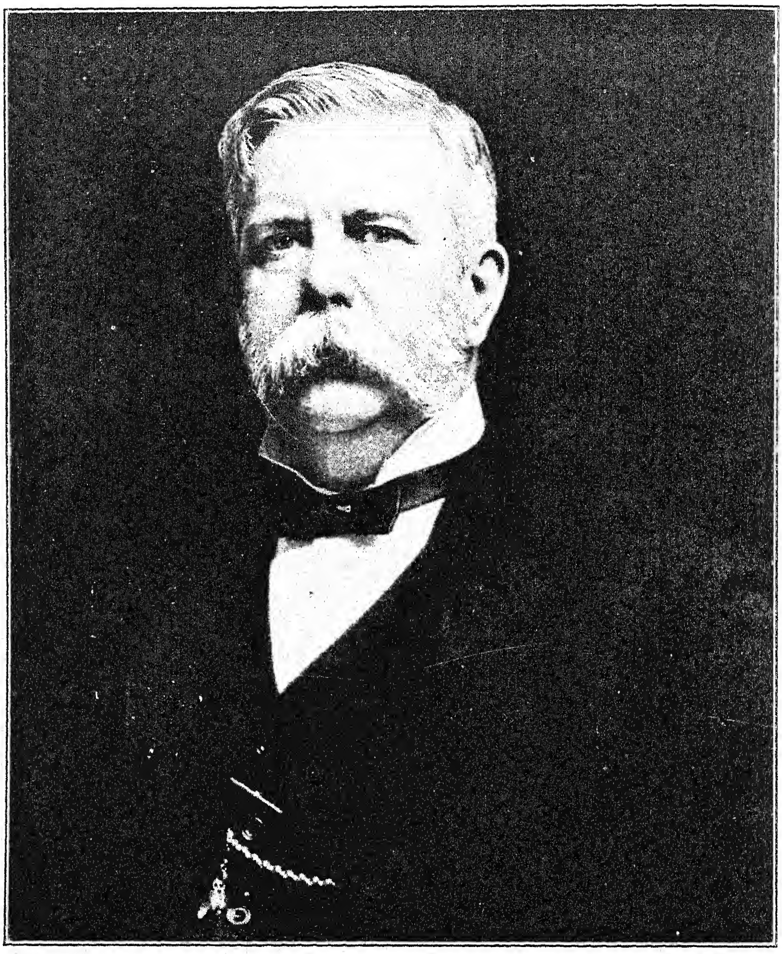
Eli Hamilton Janney was born in Loudoun County, Va., November 12, 1831. From the country schools near his home he entered Cazenovia Seminary, at Cazenovia, N. Y., and returned on graduation to the Virginia farm. With the outbreak of the Civil War he enlisted in the Confederate Army and served throughout that struggle as field quartermaster, first on the staff of Gen. Robert E. Lee and then with General Longstreet, rising to the rank of major.

The war left Janney practically penniless. He gave up his farm, moved with his family to a little home just outside of Alexandria, Va., and found employment as a clerk in a dry-goods store there. Without any special mechanical training or experience he was yet an ingenious fellow, and the problem of coupling freight trains intrigued him. The extensive freight yards in Alexandria accounted almost daily for injury to a brakeman so that the problem naturally attracted his attention. Happening one day to hook the four fingers of each hand together it flashed into Janney's mind that this involuntary action might be the clue to the solution of the coupling problem. He began immediately to whittle out small wooden models, working at night most of the time. The deeper he got into the subject the more he learned of the host of conditions that had to be considered, such as simplicity, ease of



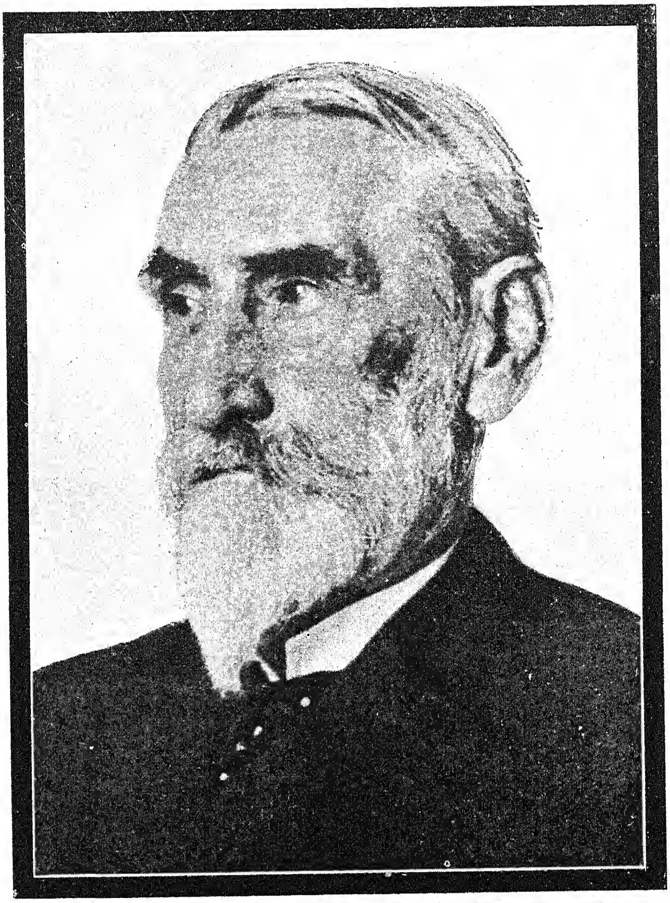
RAILROAD WRECK IN 1855

Drawn on the spot immediately after the accident. Repeated catastrophes such as this hastened the perfection of automatic air brakes and car couplers.



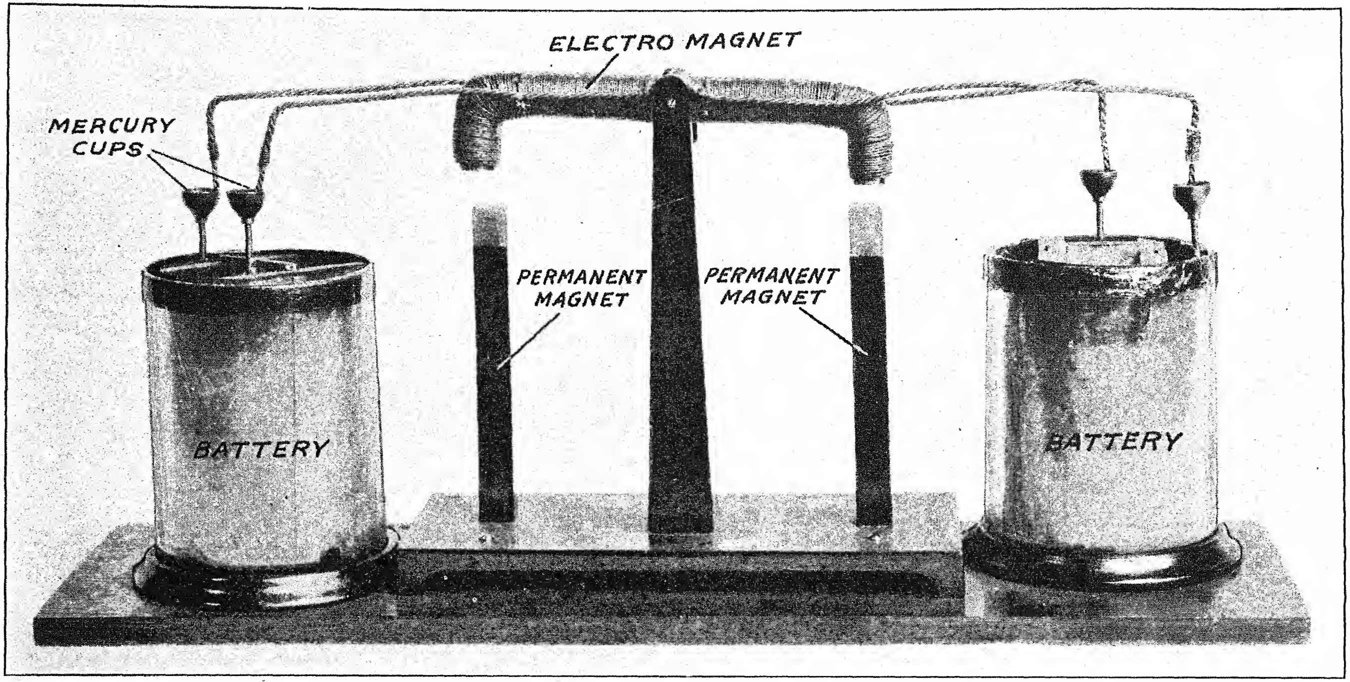
GEORGE WESTINGHOUSE, 1846–1914

Inventor of the air brake. Founder and organizer of the Westinghouse Electric & Manufacturing Co., Pittsburgh, Pa.



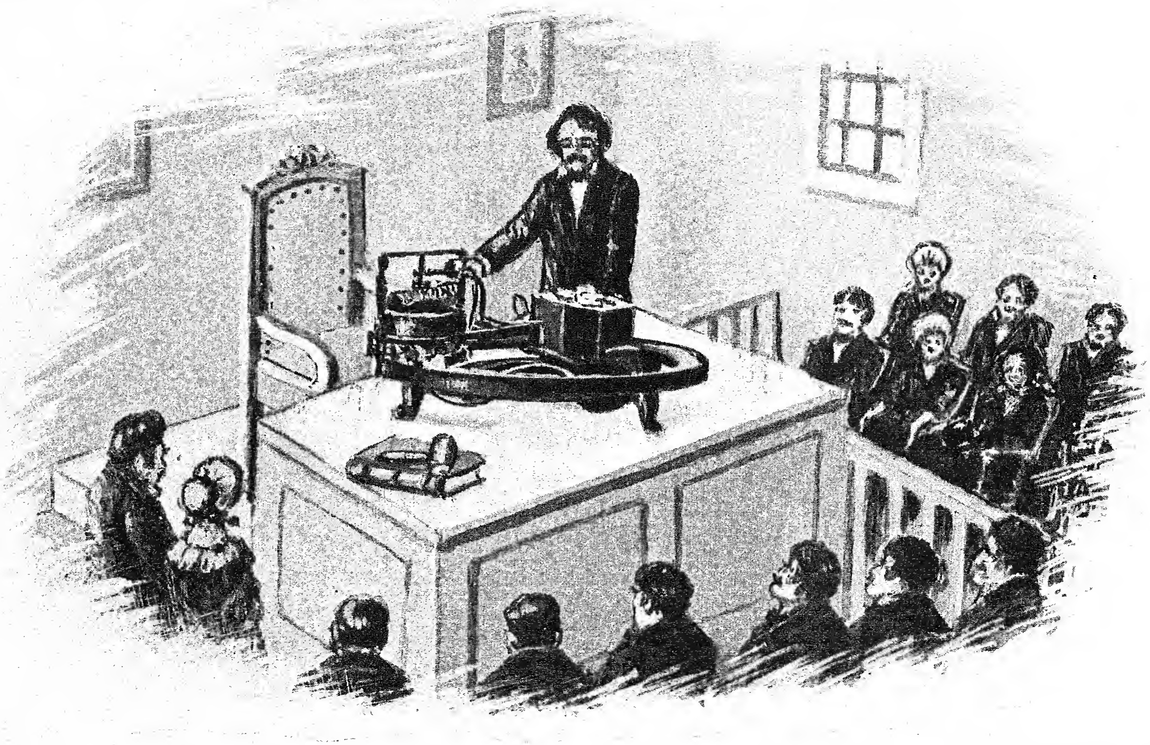
ELI H. JANNEY, 1831–1912

Inventor of the automatic coupler for railroad cars now universally used on the railroads of North America.

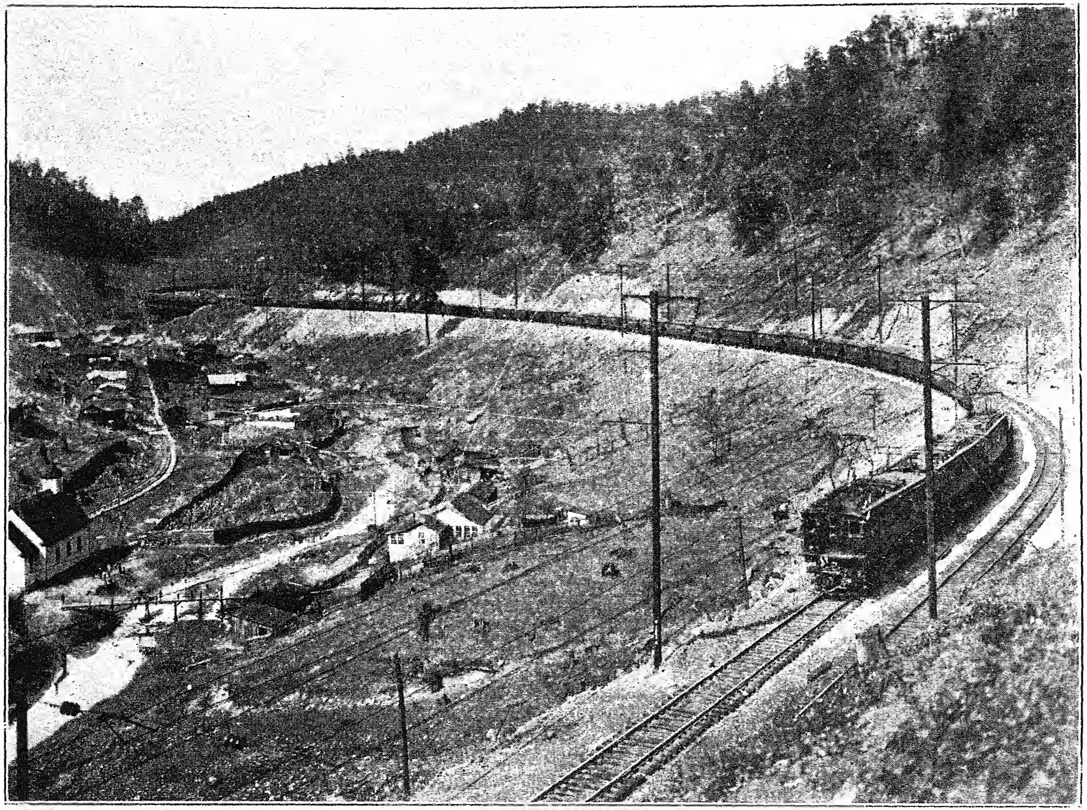


JOSEPH HENRY'S ELECTRICAL MACHINE, 1831

The first successful attempt in America to produce mechanical motion electrically. Henry supported an electromagnet on a horizontal axle like a scale beam. Alternating electrical currents (produced by dipping the ends of the magnet wires into mercury cups) transmitted through the magnet caused it to be alternately attracted and repelled by the permanent magnets and resulted in a constant seesaw motion.



DAVENPORT EXHIBITING HIS ELECTRIC RAILWAY MODEL IN THE COURTHOUSE AT TROY, N. Y., OCTOBER 14, 1835



Courtesy of Westinghouse Electric & Manufacturing Co.

ELECTRIC LOCOMOTIVE AND TRAIN, 1929

operation, strength of parts, cheapness of manufacture, and the like. Eight years passed during which he converted the clutching fingers idea into a workable mechanism of cold steel and applied for a patent. It was granted April 29, 1873.

Janney was in no position to go into the manufacture of the coupler nor had he any market for it, but with the help of friends he succeeded in making several in a local foundry and having them tried out on the old Loudoun & Hampshire Railroad. They gave full satisfaction in this test, but as Janney soon realized, this was not sufficient to attract the attention of the great railroad companies. Car-coupler inventions and inventors then were the bane of the railroad officials' existence and Janney, after a few discouraging experiences with them struck out on another tack. For 10 years he went from one iron founder to another with his coupler, improved year by year, until he found one in Pittsburgh who had sufficient faith in it to undertake its manufacture at his own expense and try to introduce it, paying Janney a royalty. Because of his perseverance he finally induced the Pennsylvania Railroad to permit the equipping of 100 cars with the coupler. Again the test proved successful.

By this time, however, coupler patents were numbered by the thousands. The most likely ones were in trial use and each had its champions among railroad men. All realized that for the betterment of the service some one form of coupler should be adopted by all railroads, but no agreement could be reached as to which one. Then, too, various cliques had been organized on different railroads in the interest of some patent, and in such cases arguments addressed to them were generally wasted. Things went along in this chaotic way for a number of years and until public indignation and the stimulus of legislation in several States and in Congress compelled railroad officers to give serious attention to the subject. The burden of making a selection fell to the Master Car Builders' Association, composed of officers of railroad companies who were in charge of car construction, A special track was laid outside of Buffalo, N. Y., in 1887, having all conceivable sorts of curves, bumps, and hollows, and every coupler maker was invited to submit his device for test.

The Janney coupler came through with flying colors and was recommended for general adoption by the association. To insure the carrying out of this recommendation completely, Janney magnanimously relinquished his rights to that part of his patent bearing on the unique curvature of the coupler jaw, so that this essential part could be made by every manufacturer. From that time on, anyone desiring to make couplers simply applied to the Master Car Builders' Association for drawings and specifications and Janney's invention became known universally as the M. C. B. To-day every railroad car in the United

States, Canada, and Mexico must be equipped with the M. C. B. or Janney coupler.

Until the time of his death, in 1912, Janney was constantly experimenting and devising improvements for the coupler, particularly for passenger cars. For years, even after his royalties ceased, he had expert mechanics in his private employ, he visualizing his ideas in little wooden models carved with a pen knife and they converting them into finished models of wood and metal. One of each of these form most interesting and valuable accessions in the railroad exhibits in the National Museum. With them is a third model of the coupler improvement devised and patented by Janney's son Robert. The latter grew up with couplers all about him and eventually became associated with one of the large coupler manufacturers, continuing in this special field until his death in 1923.

V. THE BIRTH OF THE TROLLEY CAR

For 20 years prior to his election as first Secretary of the Smithsonian Institution, Joseph Henry engaged in electrical researches, first at the Albany Academy, where he was professor of mathematics and physics from 1827 to 1833, and then at Princeton University, where he held the chair of professor of natural philosophy from 1833 to 1846. Early in his teaching career Henry used apparatus of his own construction to illustrate electromagnetic reactions. In 1825 William Sturgeon, of England, had made the first efficient electromagnet, capable of sustaining 9 pounds, to illustrate the relationship of the earth's magnetism to battery currents. Beginning where Sturgeon left off, Henry developed fundamental principles and laws upon which the modern science of electromagnetism rests. He was the first to insulate wire for the magnetic coil; he invented the "spool" or "bobbin" winding; he discovered the necessary law of proportion between the electromotive force in the battery and the resistance of the magnet. He thus worked out for the first time the differing functions of two entirely different kinds of electromagnets, the one surrounded by numerous coils of no great length, the other surrounded by a continuous coil of very great length. The former revolutionized the feeble electromagnet of Sturgeon, and by it Henry was able to lift 3,500 pounds, as compared to Sturgeon's maximum lift of 9 pounds. The latter was entirely Henry's invention and made possible for the first time the transmission of a current over a great distance with little loss. Every electrical dynamo or motor now uses the electromagnet in practically the form in which Henry left it in 1829.

Joseph Henry's concern was the discovery of truth, not the application of his discoveries. The officers of the Penfield Iron Works, at Crown Point, N. Y., however, prevailed upon him to make them

a small electromagnet shortly after his announcement of 1831. They wanted it to magnetize the iron teeth of a machine which they used to separate magnetic iron particles from refuse in iron ore. Occasionally after the magnet was received at Crown Point it was made to perform various stunts, such as holding a 100-pound anvil, for the

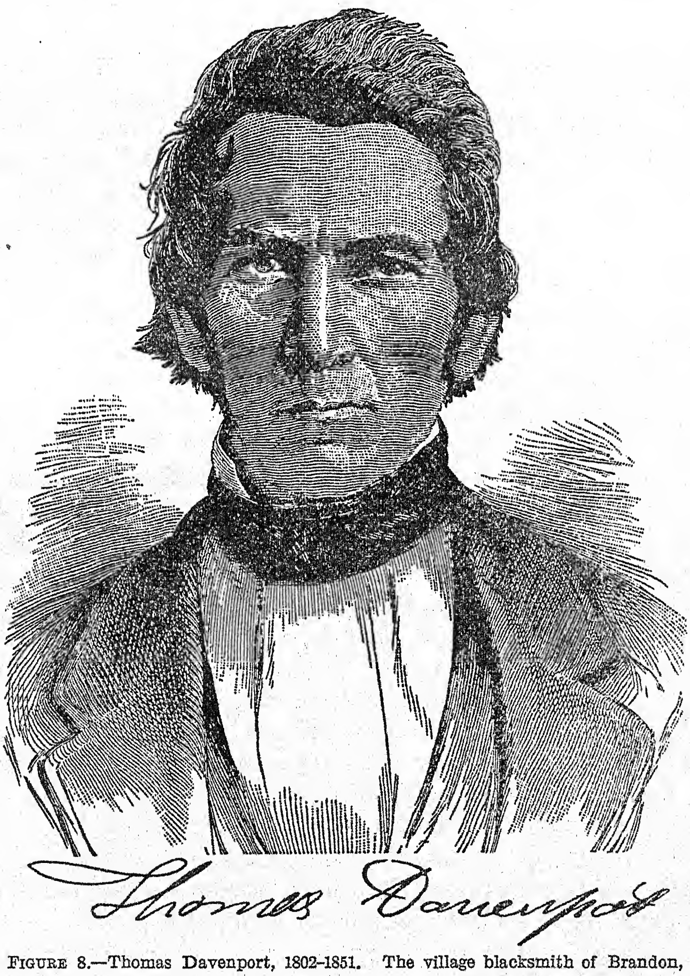


FIGURE 8.—Thomas Davenport, 1802–1851. The village blacksmith of Brandon, Vt., whose electric motor invention of Feb. 25, 1837, was the first of its kind in America

benefit of the villagers. In consequence its fame spread and the Crown Point "galvanic magnet" mystery became the chief topic of conversation for miles around.

THOMAS DAVENPORT

Twenty miles from Crown Point, in Brandon, Vt., Thomas Davenport, a blacksmith, and a studious one, and his friend Orange Smalley

chanced to hear the wonderful tale of the magnet. It was especially interesting to them for they had planned a lecture tour on scientific subjects illustrated by experiments and they were looking for good features to add to their repertory. Davenport traveled to Crown Point to see the magnet, but without success. Again in December, 1833, he went to Crown Point to purchase iron, and this time he saw the magnet and was given an exhibition of its powers.

The first question that came into Davenport's mind concerned the probable effect on the magnet if the current supply were alternately made and broken. He asked if he might try it. When permission was refused he used the $18 he had brought along to buy iron and purchased the magnet instead. He now answered his question himself, finding that as rapidly as he could make and break the current supply the magnet was charged and discharged. He realized at once that here was an available source of power. Forgetful that his wife and children depended on his blacksmithing for their daily bread, he and Smalley began experiments to develop a machine employing electromagnetism as a power agent.

In spite of his wide scientific reading Davenport was not a subscriber to Silliman's American Journal of Science and, therefore, was not aware of just what had been done up to that time by others. The same year (1831) that Henry amazed the world with his electromagnet improvements he published another paper commencing with these words: "I have lately succeeded in producing motion in a little machine by a power which I believe has never before been applied in mechanics—by magnetic attraction and repulsion. Not much importance, however, is attached to the invention, since the article, in its present state can only be considered a philosophical toy; although in the progress of discovery and invention it is not impossible that the same principle, or some modification of it on a more extended scale, may hereafter be applied to some useful purpose." That "philosophical toy" now forms one of the valuable objects in the electrical collections of the National Museum. In the Annals of Electricity, Magnetism, and Chemistry for 1834, T. Edmondson, jr., of Baltimore, Md., published the first account of his apparatus to produce continuous rotary motion by the agency of an electromagnet.

Ignorant of these efforts, Davenport and Smalley worked the greater part of 1834. They started with a permanently magnetized bar supported at its center like a magnetic needle. By placing an electromagnet approximately at the edge of the circle described by the magnet and then breaking the circuit by hand at properly timed intervals, they found that they could keep the bar in continuous rotation. From this they progressed, machine by machine, until by December they completed one of 12 permanent magnets and 2 electromagnets connected through a form of commutator consisting of wires dipping

into mercury cups to an electric battery, the whole contrivance constituting unquestionably a complete embodiment of the principles of the modern electric motor, and it revolved at a rate of speed far exceeding their fondest hopes.

While Davenport felt satisfied that he had something unusual, he wanted the opinion of a higher authority, so in January, 1835, he tramped to Middlebury College in Vermont, to show his machine to the professor of natural philosophy there. The latter was so struck with it that he urged Davenport to patent the idea and even drafted the specifications for him. While much elated and appreciative of this assistance, Davenport felt that he could improve the machine. In addition he was almost destitute. So he returned home and began another machine. This time he concentrated on the make and break or commutator mechanism, and by May, 1835, he substituted for the mercury cups insulated segments on the lower part of the wheel shaft, which were rubbed by contact springs made of flattened wire. The result was most gratifying and now appears to be the earliest instance of the use of the modern electric commutator.

Davenport now felt ready to go to Washington for his patent. Friends and neighbors gave him the money for his expenses. On the advice of the Middlebury College professor he went first to Albany and called on Amos Eaton of Rensselaer Polytechnic Institute. This authority was likewise greatly impressed with the machine and advised his showing it to Professor Henry at Princeton. Henry was delighted when he saw the model in operation, and with the courtesy which he invariably exhibited toward deserving inventors, cautioned Davenport to refrain from attempting large-scale experiments which, if they failed, would not only mar Davenport's credit as an inventor, but also stigmatize the electromagnetic engine as a humbug. He gave him a certificate in which he spoke highly of the novelty and originality of the invention. Also just before Davenport left he gave him the shock of his life by showing him his own little electromagnetic seesaw engine. This was Davenport's first intimation that anyone prior to himself had even conceived the possibility of producing motive power by electromagnetism. On Henry's advice Davenport next stopped in Philadelphia and operated the machine for Alexander Bache, professor of natural philosophy at the University of Pennsylvania, and also for a large group of men assembled at the Franklin Institute. From there he went on to Washington, only to find to his dismay, that he hadn't enough money left to pay both for the preparation of his patent application and his carfare home. Dispirited and despondent he retraced his steps, sold his machine on the way to Rensselaer Polytechnic Institute for $30, and returned to Brandon in no happy frame of mind, fully resolved to abandon what his friends called "visionary schemes."

Professor Eaton at Rensselaer had other ideas, however. He published an account of Davenport's machine in a Troy paper. Other papers copied it and there followed all manner of critical comments implying trickery and the like. Eaton determined to give a lecture at which Davenport himself would appear and demonstrate his machine. Hopelessly in debt, the inventor was in no mood for further experiments with the invention which had ruined him, but he eventually succumbed to Eaton's pleadings and admonitions. He determined to construct an entirely new machine adapted to railway locomotive purposes. By working night and day he completed it in time to appear with Eaton at his public lecture in the court house at Troy on the night of October 14, 1835. A large and for the most part sympathetic audience listened patiently to Eaton's discourse but when Davenport appeared and set his little model in motion on the judge's bench the applause was intense. Many must have realized that they were witnessing the first demonstration in history of transportation by electricity. What the audience saw was a sort of minature merry-go-round, 24 inches in diameter, with a little electric motor revolving horizontally. Through little gears it drove round and round on the circular track a 3-wheeled framework to which the motor was fastened. The wheel framework was pivoted at the center of the merry-go-round, where on a little platform was also the zinc-plate battery from which wires extended to different points of the motor.

The reception he had received inspired Davenport with confidence that he would be able to secure the necessary capital to patent his invention, and to build full-sized machines. His first partner's enthusiasm soon dwindled. Then he joined Ransom Cook who furnished the money to build new and always more powerful models and to give exhibitions throughout New England. Presumably the partners were able to sell their old models as improved ones were built, for one of them, a working model of the electric railway made about 1836, came into the possession of the Troy Female Seminary. Many years later it was presented to the American Institute of Electrical Engineers, which in turn presented it to the National Museum in 1898. Since then it has been on exhibition in the Museum's engineering section.

The year 1835 and almost the whole of 1836 passed without any material success in the way of electric motor or railway business. Davenport had been able to raise enough money to build a model of his electric motor and make application for a patent, but the Patent Office fire of December 15, 1836, destroyed both the model and all of the papers relating to his application. With Cook's help he tried again, submitting another model, and this time received his patent on February 25, 1837. For years the model was kept in the Patent

Office, but since 1908 it has formed one of the interesting objects of the electrical collections in the National Museum. Just a few months after receiving this patent, Davenport and Cook were hypnotized by the soft words of a New York "promoter" to form a joint stock company to exploit the patent. A year later they found themselves minus $5,000 of their own money which they had spent in experiments and in the construction of progressively more practical motors, and the promoter gone.

Cook gave up in disgust, and Davenport, again alone, tried for four or five years longer to maintain public interest, in the hope of finding capital to establish an electric-motor factory. He sent a representative to England and France to obtain patents, and also to exhibit both his motor and railway; he undertook to publish a technical journal called "The Electro-magnet and Mechanic's Intelligencer," printing the paper on a press operated by one of his motors. After two or three issues he gave that up. Finally, early in 1843, his nervous system enfeebled by so many years of incessant toil and anxiety and lack of proper nourishment gave way under the strain and he became dangerously ill. He recovered, but his constitution was permanently impaired, and after residing two or three years longer at Brandon, he retired to a small farm in Salisbury, Vt., where he passed the few remaining years of his life, dying July 6, 1851, just 49 years old.

Like Fitch and Rumsey, Davenport was ahead of his time. The steam engine and locomotive were just coming into their own in the public regard and conditions had not yet arisen demanding other forms of power. As a matter of fact, more than 30 years passed after Davenport's death before either the electric motor or the electric railway became actualities. When they did they were Davenport's ideas with incidental improvements.

VI. THE COMING OF THE AUTOMOBILE

The year that James Watt obtained his important steam engine patent (1769) a French Army engineer, Nicholas Joseph Cugnot, built and operated his third steam carriage. It was really a tractor and was used for a short time to pull heavy artillery. This was the world's first successful self-propelled vehicle on common roads. In 1784 one of Watt's representatives, William Murdock, made a small working model of a high-pressure steam carriage which performed very well. As a result he tried to have Boulton & Watt go into the manufacture of steam carriages, but Watt would have none of it. In a letter to Boulton in 1786 he wrote: "I am extremely sorry that William still busies himself with the steam carriage. In one of my specifications (patent) I have secured it as well as words could do it according to my ideas of it; * * * I have still the same opinions concerning it that I had; but to prevent as much as possible more fruit-

less argument about it, I have one of some size under hand, and am resolved to try if God will work a miracle in favor of these carriages. I shall in some future letter send you the words of my specification on that subject. In the meantime I wish William could be brought to do as we do, to mind the business in hand, and let such as Symington and Sadler throw away their time and money hunting shadows." These remonstrances seem to have had the desired effect of bringing Murdock to abandon his ideas, but for over a hundred years thereafter, first in Europe and later in the United States, inventors designed and built steam carriages, wagons, and coaches. Each succeeding decade showed improvements in this mode of locomotion over the preceding one until it seemed a foregone conclusion that steam would displace the horse as the motive power on highways.

Meanwhile, however, a number of other inventors were quietly experimenting with another form of power—exploding gases in an engine cylinder. Way back in 1678 the Dutch astronomer, Huygens, had attempted this, using gunpowder, and in 1794 an English inventor, R. Street, had obtained a patent on an explosive engine using gases distilled from turpentine. Five years later a French mechanic, Le Bon, invented a similar engine using street-lighting gas and an electric spark to ignite it. After that an increasing number of individuals took up the task of devising a practical engine of this type. In the United States, Stuart Perry, of New York, patented his ideas of such engines between 1844 and 1846. They included both the air and water cooled types and used turpentine gases as fuel. Alfred Drake, a Philadelphia physician, patented an "ignition-gas engine" in 1855, exhibited a full-sized one at the American Institute Fair in New York that year, and even advertised engines for sale. It is not known whether any of these were actually ordered or put into service.

The succeeding decade saw even more rapid progress. In 1860 Jean Joseph E. Lenoir in France designed, patented, and built the first practical gas engine, for which he was decorated by the Academy of Sciences. That invention set on foot in Europe a prosperous industry building gas engines. They burned street gas and took the place of stationary steam engines. Little or no thought was given to the possibility of adapting the new gas engines to road vehicles. But with the unexpected discovery in the United States of an ample quantity of a preferable fuel, the new industry was brought up short, changed direction, and headed for the conquest of the open road. Col. Edwin L. Drake had succeeded in 1859 in drilling an oil well near Titusville, Pa., and tapping a petroleum reservoir from which flowed 1,000 barrels of oil a day. It had been known for some time that petroleum contained light liquid fuels which were even more practical than gas for an engine, but there was so little petroleum available that its use received but little attention. Drake's success

changed all this. The first oil boom began and daily new wells came in, yielding additional thousands of barrels of oil. The last stumbling block to the development of an oil engine had been removed and inventors buckled down to the task.

George Brayton in Boston, with almost 20 years' study of and experiment with explosives back of him, devised and patented his oil engine in 1874. In 1876 N. A. Otto, of Cologne, Germany, obtained his American patent for the 4-cycle gasoline engine—the type now universally used for automobiles. George B. Selden, of Rochester, N. Y., filed his application for a patent on a gasoline-engined horseless carriage in 1879, using a Brayton type engine. Gottlieb Daimler, of Germany, produced the first lightweight, high-speed gasoline engine around 1883, and on March 4, 1887, harnessed it to wheels and successfully ran the first gasoline-propelled vehicle.

Daimler's accomplishment proved a revelation of the possibilities in highway transportation. Soon others were following his lead: Benz in Germany; Napier, Lancaster, Royce, and Austin in England; and Peugeot, De Dion, Renault, Bollee, Panhard, and Levassor in France. Before yielding to others, Panhard and Levassor evolved the present-day automobile, the chassis separate from the body; the engine placed upright and in front under a hood; the clutch and transmission gears back of the engine; and chain drive to the rear wheels. Except for the substitution of shaft for chain drive their design of 1895 is practically the same as that of the automobile of 1929.

Americans were by no means asleep during these stirring times in Europe and were only a little behind their foreign contemporaries in building and successfully running gasoline vehicles. Although Selden was the first to announce publicly his intentions in this direction by applying for a patent, he spent his time in juggling the application and keeping it alive in the Patent Office for 16 years and did not construct a single machine during this time.

Two middle westerners, on the other hand, Charles E. Duryea and Elwood G. Haynes, went at the problem the other way round—building machines first—and it was the successful performance of Duryea's cars, followed almost immediately by those of Haynes, that made the gasoline automobile a reality to the people of the United States. The manufacture and sale of their first machines mark the beginning of the great American automobile industry.

CHARLES E. DURYEA

On his father's farm, 4 miles from Canton, Ill., Duryea was born December 15, 1861. His boyhood came just at the time when machinery was being rapidly adopted for farm use so that he became quite familiar with a wide variety of mechanical devices. Transportation had always fascinated him, however, and almost as soon as he

learned to read he obtained what books and magazines he could on the subject. When in his teens, velocipedes came into vogue and from descriptions in some magazines he built one out of old carriage wheels. A short while after that he went to what was known as a seminary, and for his graduation thesis in 1882 he chose the subject "Rapid transit," discussing transportation on land, on water, and in the air.

Duryea taught school for a year and then tried his hand at the carpenter and millwright trades for a while. Later he went to St. Louis and got a job in a bicycle-repair shop. Three years later he was selling bicycles of his own design and made by several manufacturers. He continued in the bicycle business for over 10 years both in St. Louis and in Washington, D. C., and as a side line, was a licensed steam engineer. He helped a Washington inventor construct a steam bicycle and tricycle, but he could not work up much enthusiasm for these because of another type of engine which he had seen. At the Ohio State Fair at Columbus in 1886 he had had an exhibit of his bicycles. Next to his stand a gasoline engine had been exhibited, the first he had ever seen. It was a clumsy affair weighing about a ton, although only developing 2 horsepower. The carburetor consisted of a tin tank larger than a wash boiler stuffed with excelsior. Duryea felt that in time this engine would be refined into a more portable unit. Nor did he have long to wait, for that same year he read of Daimler's newly patented light-weight engine. By 1891 he concluded that the public would be ready to buy horseless carriages as soon as he could make them.

That summer he went to Springfield, Mass., where the Ames Manufacturing Co. was making bicycles for him, and while the plant was shut down in August began some gasoline-engine experiments. Daimler engines were then available in the United States but they seemed too big and heavy for Duryea's purpose. While his brother Franklin, a toolmaker for the Ames Co., conducted the experiments, Charles, with a pencil figured and sketched and sketched and figured for the rest of the year on a design for a gasoline buggy. At last he employed an artist to make two pictures of the contraption, based on his descriptions and sketches.

Armed with these pictures, Duryea set out to raise money to build the machine. Luckily he found a man in Springfield willing to risk some of his, so Duryea set to work early in 1892. First he hired a draftsman to make detailed drawings of the various parts. Then he let contracts to make the parts. He rented the second floor of a machine shop in March. He purchased and brought to the shop a lady's phaeton, with top, regulation oil lamps, whip socket, and so on. Assembling began as soon as the parts started to come in. With the completion of each unit for the buggy it was tested and any changes

thought desirable were made, but by September 12, 1892, it was so nearly completed that the engine was cranked up and the machine operated on the shop floor to find out "how powerfully it pulled." When fully assembled the next month, test runs were made in an empty lot adjoining the shop and also on the streets of Springfield at night when there were less horses to scare.

While the carriage did not stall, the engine proved disappointingly low in power, so that shortly after these October trials the machine was taken back into the shop, the engine torn out, and a new one started. Duryea felt, too, that heavier parts were needed about the rest of the vehicle so he dismantled the whole during the winter and started a second one immediately. Following the same design as the first, the second carriage was finished late in the summer of 1893 and successfully tried out on the road in September of that year. Thirty years later this same machine came to light in a barn in Springfield, Mass., covered with dirt, its metal parts thick with rust, and its leather dashboard stiff and hard. The National Museum was immediately notified and, disheveled as it is, it now proudly heads the line of historic automobiles there.

The successful demonstrations of these first horseless carriages did not suffice to cause the public to sell its horses and rush pell-mell to Duryea with orders. Oats were still too cheap. Duryea also realized after seeing a Daimler car and an electric vehicle at the World's Fair in Chicago, that he had aimed too low in putting out a machine to sell for $500, so he and his brother began immediately on a third, this time a "quality" car.

As with the earlier carriages, this one went through much preliminary experimenting with engines, transmissions, electric ignition, and the like, but eventually, in March, 1895, a 2-cylinder, pneumatic-tired buggy was on the road. It was immediately turned over to a promoter who used it almost daily during that spring and summer in attempts to seduce capital to start an automobile business. Even with this green driver it never failed once. It had some of the features of the modern automobile such as a water-cooled engine with water pump, a bevel-gear transmission with three speeds forward and reverse, electric ignition, and, like the preceding cars, it had a rigid front axle with steering knuckles at the ends. It was steered by a tiller handle, the up-and-down motion of which changed the speeds—"one hand control."

On Thanksgiving Day, 1895, America's first automobile race took place, the run being over snowy roads from Chicago to Waukegan, a distance of 52 miles. Duryea entered this same machine and won the race and the money prize. It was the only car in the race (the others were foreign makes or electrics) to cover the distance without being pushed and to return to its garage the same day.

In the meantime the Duryea Motor Wagon Co. had been organized in Springfield Mass., and during the winter of 1895–96 13 motor carriages were built and sold—the first automobiles to be regularly made for sale in the United States. Thus the great ambition of America's pioneer automobile manufacturer, Charles E. Duryea, became an accomplished fact.

ELWOOD G. HAYNES

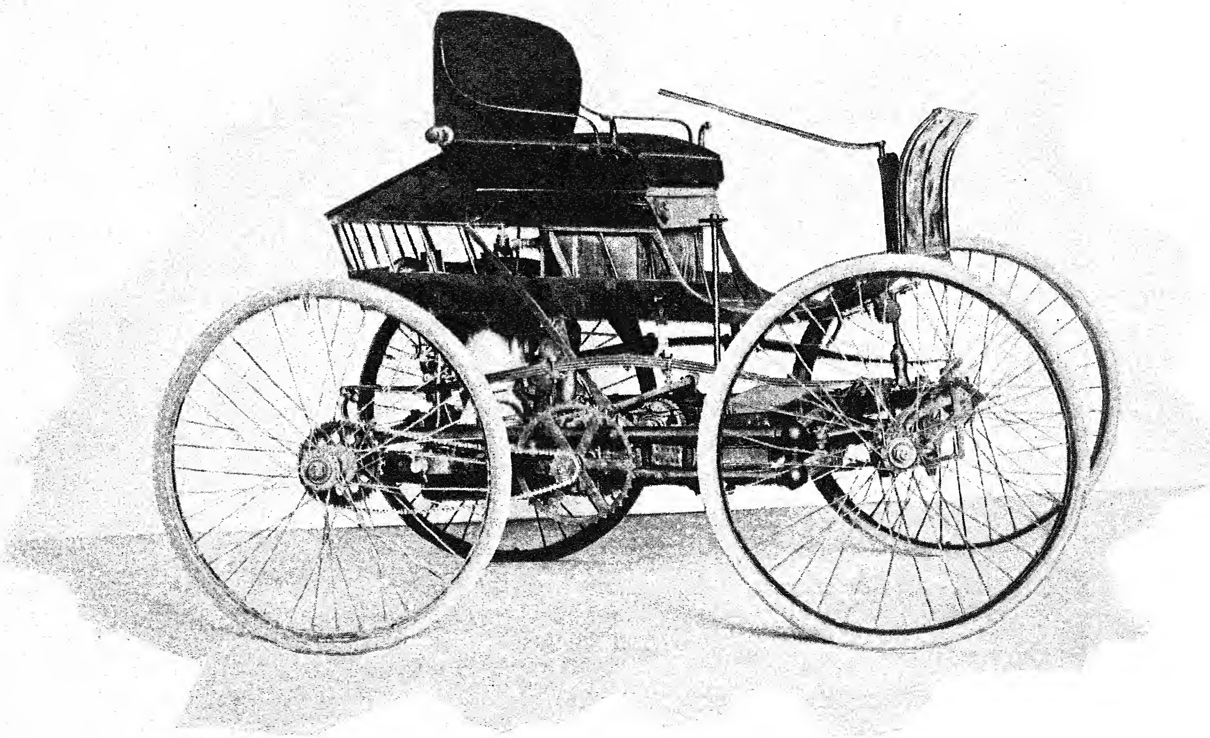
If an automobile could have been purchased anywhere in the United States in 1890, it is more than likely that Elwood Haynes would never have had the notion of building one. He was engaged in the production of oil and gas and his duties obliged him to travel constantly with a horse and buggy. He wanted a faster conveyance and could not find one, so he undertook to make one for himself. Haynes was born in Portland, Ind., on October 14, 1857. When he was 14—that experimental age—someone gave him a book on chemistry. What he subsequently read fascinated him to such an extent that he tried to carry out some of the experiments described and with the crude apparatus he could devise he made oxygen gas, hydrocloric acid, and a few other things. That serious play gave the first clue to his ingenuity; it started him on an inventive career; and it brought about the decision to make chemistry and metallurgy his life work.

Haynes prepared for college and entered Worcester Polytechnic Institute at Worcester, Mass., in 1877. His thesis on graduation dealt with The Effect of Tungsten on Iron and Steel. He returned home, but three years later he enlisted in a postgraduate course at Johns Hopkins University in chemistry and metallurgy. A year later he became the science teacher in the Eastern Indiana Normal School at his home in Portland and taught for three years. Just about that time the natural gas and oil business began to boom around Portland. Haynes joined the new industry and from 1889 to 1892 he served as manager of the Portland Natural Gas & Oil Co. Visiting the company's wells by horse and buggy proved too slow for him and led him to seek a speedier substitute.

Haynes considered three possible sources of power—steam, electricity, and gasoline. He soon eliminated the first two. No machine shop existed in Greentown, Ind., and no facilities of any kind for building a machine, so that he was restricted to the drawing of a few sketches of possible mechanisms. In 1892, however, he moved to Kokomo, and soon afterward made some rough sketches of a self-propelled vehicle. In the fall of 1893 Haynes bought a single-cylinder, 1-horsepower gasoline engine, made by the Sintz Gas Engine Co. of Grand Rapids, Mich. Next, after much deliberation and examination of various styles of carriages, he purchased a single buggy body as

DURYEA AUTOMOBILE, 1892–1893

Designed and built by Charles E. Duryea at Springfield, Mass., and successfully operated in the summer of 1893.



HAYNES AUTOMOBILE, 1893–1894

Designed and built by Elwood Haynes at Kokomo, Ind., and successfully operated July 4, 1894.

being best suited for his proposed vehicle. He had considered the problem of putting together the two units which he had already purchased into a workable whole, and had his plans rather completely worked out before deciding in which of the machine shops of Kokomo he would have the work done. But late in the autumn he made financial arrangements with Elmer Apperson, proprietor of the Riverside Machine Works, to do the work. Haynes stood alone in having faith in the successful development of his idea, and it was only upon his assuming full responsibility for the success or failure of the machine that Apperson would take on the job.

His first disappointment came when he realized that the heavy vibration of the engine was far more than the buggy he had bought could stand and that a special framework would have to be constructed. Accordingly a hollow square of steel tubing was made and the buggy seat, floor, and dash secured to it. The rear cross member of the square constituted the rear axle and the engine was swung within the square and just in front of the axle. By means of sprocket chains the engine power was transmitted to a countershaft forward beneath the seat and from there back to the rear wheels by another set of chains. As the work progressed, Apperson and his brother Edgar, a bicycle-repair man, became more and more interested in the machine and numerous suggestions made by them pertaining to the mechanical arrangement as well as the mode of construction were incorporated. A flat rectangular gasoline tank was installed under the floorboards, while the water tank for cooling found a place under the seat cushion with a small rubber hose connecting it to the engine. The machine had no radiator. The engine was started by cranking from the side, the crank being poked between spokes of the right rear wheel.

By the 1st of July, 1894, the machine stood ready for the finishing touches. It had solid rubber-tired wire wheels and a tiller handle steering mechanism. On July 4 Haynes decided to give it a road test. Word got out about his plans and so many people crowded around the Apperson shop when the much talked-of horseless carriage was pushed into the street that Haynes decided to hold his test outside of the city. A horse-drawn carriage pulled the machine 3 or 4 miles out into the country. For safety's sake the faithful horse was first driven some distance to the rear. Then they cranked the engine, Haynes and Apperson got aboard, Haynes threw in the friction clutch, and the horseless buggy moved forward out Pumpkinvine Pike. For a mile and a half two delighted men "flew" at an estimated speed of 6 or 7 miles an hour, then turned the machine around and drove all the way into town and to Haynes' house without a stop.

Haynes now had the horseless carriage he had been looking for since 1890. He abandoned the gas business and busied himself about the commercial possibilities of this new transportation agent. Haynes

entered his car in the Chicago auto race of 1895 and drove it there for the meet. Though he did not win the race he did get a prize of $150 for having the best-balanced motor of any of the machines there. In 1898 he organized the Haynes-Apperson Automobile Co., and built 50 cars that year in spite of the warnings of advisors that the horseless carriage was only a plaything for the wealthy. After four years as president of this company he became president of the Haynes Automobile Co., serving in this capacity for a number of years but eventually retiring to resume his work in metallurgy. In this field he continued actively until his death in 1926. Even when president of the automobile company, Haynes gave his main attention to the metallurgical side of the industry. He was a pioneer in the introduction of nickel, steel, and aluminum in engine construction and also was much interested in the improvement of the carburetor.

For upwards of 16 years Haynes cherished his first horseless carriage but in 1910 he reluctantly parted with it to the National Museum where it now stands second in the line of America's pioneer automobiles.

SUMMARY

Approximately 2,000 years elapsed between the time that steam was first brought to man's attention by the philosopher, Hero, and the time that it was put to practical use. Then began the industrial revolution and in one-tenth of the time since, the world has reached its present high plane of mechanical civilization. In England, the economic necessity of removing water from her coal mines stimulated inventive action, while the need of better transportation facilities to hold together a vast territory to be, was the spur in America.

To-day two-fifths of the railroad plants in the world are within the boundaries of the United States as well as four-fifths of the world's motor cars—facts which indicate the vast extent to which the people of America use transportation.

THE SERVANT IN THE HOUSE: A BRIEF HISTORY OF THE SEWING MACHINE

By Frederick L. Lewton
Curator, Division of Textiles, United States National Museum

[With 8 plates]

The Song of the Shirt

With fingers weary and worn,
  With eyelids heavy and red,
A woman sat, in unwomanly rags,
  Plying her needle and thread,—
Stitch! stitch! stitch!
  In poverty, hunger, and dirt;
And still with a voice of dolorous pitch—
  Would that its tone could reach the rich!—
She sang this "Song of the Shirt!"

—Thomas Hood.

WHY THE SEWING MACHINE WAS INVENTED

The sewing machine, like most important inventions, was the result of the needs of its time and was thought out and brought into practical reality when the demand became acute for more speed and increased production in the manufacture of garments. The poverty of England's seamstresses as told in Hood's The Song of the Shirt, the need of uniforms for clothing the army in France, and the periodically sudden needs for garments by the whale fishermen of New Bedford and other New England fishing ports, all were reflected in attempts to improve upon sewing by hand. When these various attempts did appear they attracted but little attention at first except from those who feared their means of earning a living would be taken from them if a machine to sew would become a possibility. The machines of Barthelemy Thimonnier engaged in sewing uniforms for the army in France were destroyed by a mob, and the development of what promised to be America's first practical machine (that of Walter Hunt in 1834) was laid aside for fear of taking the bread out of the mouths of the seamstresses.

Even though sewing machines formed one of the most interesting exhibits at the "great exhibition" in the Crystal Palace at London

in 1851, the important part they were to play in the life of the people of the whole world was so little appreciated that no mention was made of them in the long list of achievements discussed by writers of the time. A series of reviews and essays under the general title of Gifts of Science to Industry, which appeared in the London Times during the progress of the "great exhibition" in 1851, discuss the outstanding achievements of the times as shown at the exhibition but make no mention of the sewing machine.

While the first idea of a sewing machine appeared in England the credit for producing the first practical machine belongs to Americans. The possibility of sewing by machinery was practically demonstrated over 100 years ago; but it required the combined efforts of a generation of inventors to improve the sewing machine so as to make it really a labor-saving instrument. Its history is a record of rapid advancement in mechanical movements and combinations of devices, which had apparently never been thought of until the close of the eighteenth century. While a great many people have contributed, by their powers of invention, to the present perfection of the sewing machine, and are therefore entitled to due honor and praise for the results of these labors, still the names of Thomas Saint, Barthelemy Thimonnier, Walter Hunt, Elias Howe, jr., Allen B. Wilson, Isaac Merrit Singer, and James E. A. Gibbs, must always be recognized as those of men in whose minds the idea of a sewing machine was first conceived in anything like the form in which it has been preserved until now, and whose early crude productions contained any of those features that have been found to be essential after so many years of improvement and progress.

The fascinating story of the invention of this most useful household servant is best told by revealing a few incidents in the lives of several of these great inventive geniuses who contributed most to make machine sewing practicable. Thimonnier, Hunt, Howe, Wilson, Singer, and Gibbs—among the thousands who have spent months and years of effort to improve upon the hand method of sewing, these six stand out as shining stars of great brilliance in a firmament already bright with hosts of others.

THOMAS SAINT

The idea of a machine that would use a needle and thread for the purpose of sewing together two or more pieces of cloth or leather after the manner in which this had been done by human hands for thousands of years appears to have been first thought out by an Englishman, Thomas Saint, who in 1790 received a patent for a machine for sewing leather. His drawings show certain features which are essential to the sewing machines used to-day, but so far as known Saint's idea was not put to any practical use by him.

BARTHELEMY THIMONNIER

Thirty-five years later, a poor French tailor, entirely ignorant of the principles of mechanics, became so absorbed with the idea of producing a machine to sew the seams of garments, that he spent four years endeavoring to make it sew, only working at his trade enough to obtain for his family the barest necessities of life. He worked alone and in secret and so neglected his business that he was looked upon as little more than crazy. By 1829 he had mastered the mechanical difficulties and had produced a sewing machine which made the chain stitch by means of a hooked needle like a crochet needle. The next year he was given a patent on his machine and soon attracted the attention of a skillful engineer who took Thimonnier and his machine to Paris. By 1831 he had made so much progress that he was made a member of a prominent clothing firm and had 80 of his sewing machines at work upon uniforms for the French troops. But the tailors looked upon the new invention as a dangerous competition and an infuriated mob smashed every machine they could find, forcing the inventor to flee for his life. We see poor Thimonnier trudging homeward from Paris with his sewing machine on his back and exhibiting it as a curiosity for a living. Later he tried to provide for his family by selling handmade wooden machines for $10 each. He kept on trying to perfect his machine and by 1845 he had so improved it that he was able to sew at the rate of 200 stitches per minute. At this time he obtained the help of a friend named Magnin to manufacture the machines, and he soon had a machine capable of sewing all kinds of fabrics from fine muslin to leather. The revolution of 1848 put a stop to his sewing-machine business and Thimonnier went to England for a short time. Together with Magnin he secured a patent for his machine in England in 1849 and the next year the United States granted him one, but by this time other inventors had entered the field with more practical machines.

Thimonnier sent his machine to the Universal Exhibition in London in 1851, but through a mistake it was not seen by the judges and no attention was paid to it. This greatly discouraged him and although he continued to work with his machine for a few years his lifelong struggle had exhausted him and he died in poverty in 1857, aged 64 years. When we see Thimonnier's lifelong effort and bitter struggles continued in spite of so many failures, we must believe that the man was possessed of more than an ordinary share of energy and perseverance, and that his failure to popularize his machine was due to the times in which he lived and the people among whom he sought to introduce it. In one sense his life was a total failure, for he reaped none of the wealth which was showered upon many of the pioneers in the sewing-machine trade; but before he died he had the realization

of his lifelong dream—that of seeing the sewing machine recognized as one of the most efficient labor-saving inventions of our civilization and its manufacture and sale a prosperous business.

WALTER HUNT

About the time that Thimonnier had so developed his invention that 80 of his machines were sewing for the French Army, an inventive Quaker genius in New York City was turning his attention to a sewing machine. This man, Walter Hunt, was then 39 years old and already had to his credit a number of useful inventions such as a flax-spinning machine, a knife sharpener, gong bells, a yarn twister, the first stove to burn hard coal, etc. From 1835 to the year 1859, when he died, Hunt had invented a greater number and a greater diversity of fundamental original ideas than any known man of his time, which in their original or some modified form are in use to-day. Among his inventions of this period were the following: Machinery for making nails and rivets, ice plows, velocipedes, a revolver, a repeating rifle, metallic cartridges, conical bullets, paraffin candles, a street-sweeping machine, a student lamp, paper collars, and the safety pins which mothers find so indispensable in the nursery. His friend J. R. Chapin, a draughtsman, who prepared many drawings to accompany Hunt's application for patents, says of the safety pin, that it was thought out, a model made of an old piece of wire, and the idea sold for $400, all within the space of three hours, in order to pay a debt of $15 which Hunt owed him.

In addition to possessing a marvelously original and inventive turn of mind, Hunt was a diligent student and had an extensive acquaintance with the mechanical and scientific literature of his time. Somewhere between the years 1832 and 1834, Walter Hunt made in his shop on Amos Street, New York City, a machine "for sewing, stitching, and seaming cloth." This first machine was quite successful, so that others like it were built by the inventor assisted by his brother, Adoniram.

Many samples of cloth were sewn by these machines, and friends and neighbors of the inventor came to see them work. While Hunt's machine could not be made to do curved or angular work, nor sew a continuous seam for more than a few inches without removing and readjusting the cloth, it was capable of doing certain classes of work with speed and accuracy and to that extent must be regarded as a practical success, even though it was still incapable of the general adaptation which sewing machines afterwards attained. Walter Hunt's invention, however, contained nearly all the essential parts of the best modern machines. He used an eye-pointed needle, moved by a vibrating arm, working in combination with a shuttle carrying a second thread so as to make an interlocked stitch fully as well as

it is done by our present improved machines. The cloth feed was no doubt imperfect, which thus made the machine of little practical value, but for all that it was a step in the right direction, and was undoubtedly the pioneer of the present sewing machine, and far in advance of anything which had been done before it.

In 1834, Hunt had sold a half interest in his machine to George A. Arrowsmith, a blacksmith, who conducted the Globe Stove Works on Gold Street, New York City, and was the employer of Walter Hunt's brother, Adoniram F. Hunt. At the request of Arrowsmith, Adoniram built a second machine of wood according to Walter's plans which so impressed Arrowsmith with its value that he bought the other half interest in the invention from Walter Hunt, with the intention of developing it, Hunt agreeing to assist him in preparing drawings for the securing of a patent. Financial difficulties, the opposition on religious and moral grounds of friends of the hosts of hand sewers, who would thus be deprived of a means of livelihood, and the realization of the size of the undertaking comprised in manufacturing and selling such a machine, discouraged Arrowsmith from doing anything with his purchase from Hunt. In the meantime, in 1835, Arrowsmith, who had business interests in Baltimore, sent Adoniram Hunt there. Adoniram took with him his sewing machine and demonstrated it to his friend, Joel Johnson, with whom he was staying. The next year he writes to Johnson: "I made that sewing machine that I had at your house work to a charm," and adds that he desires to build a stronger machine, all of iron.

In 1838, Walter Hunt suggested to his daughter Caroline, then a girl about 15 years of age, that she engage in the business of manufacturing corsets with the aid of the sewing machine made by him. After discussing the matter with older women, experienced in the business, Miss Caroline declined to go into the business and use the new invention to perform the difficult heavy stitching required, for the sole reason that the introduction of such a machine would be injurious to the interests of hand sewers, and would be very unpopular.

The invention appears to have dropped completely out of sight until the successful introduction of sewing machines drew attention to it some 15 years later, when a search for the old machines resulted in the discovery of essential parts of both of the Hunt machines in a garret in Gold Street, New York City, where they had been thrown among a lot of rubbish recovered from a fire.

Hunt himself, like most inventors, was then working on other ideas and was satisfied that he had invented, built, and put into practical operation, a machine capable of doing mechanical sewing with speed and precision, and having sold the invention—as he had many others—for a mere trifle, felt at that time no further urge to manufacture it. He later bought back from Arrowsmith his entire interest

in the invention and in 1853 built a third machine after his original plans, for the demonstration of his principles of sewing in a famous suit for infringement of patent rights. It was characteristic of him that he was all the time too much occupied with turning out new inventions to pay any attention to the development of the old, or to make the necessary efforts toward securing for himself a fair share of the profits derived from them. It was his misfortune that although he was a great inventor who could conceive ideas and mold them into practical shape, he was otherwise as simple as a child and lacked sufficient business sense to lead to success. He usually made his contracts in a loose and careless manner, was reckless and extravagant in spending and always in want of money, so that his inventions were usually sold before they were patented. Hunt's machine was undoubtedly the pioneer of the present sewing machine. It was his misfortune that his brain was too full of other and later inventions to admit of his pursuing this one to a successful development and that he did not reap his share of the splendid rewards which were showered so lavishly upon others. Let us not for that reason deprive him of what he is justly entitled to claim, the credit of having been the inventor of the first sewing machine which contained all the elements of practical and commercial success.

ELIAS HOWE, JR.

How often it is that a chance remark falls upon receptive ears other than those to which the remark was addressed, and brings forth astonishing results. In Boston, in 1839, an undersized, curly-headed youth of 20, gravely listening to an argument over the operation of a knitting machine between two men and his employer in a machine shop, heard the latter say: "What are you bothering with a knitting machine for? Why don't you make a sewing machine"? "It can't be done," said one. "Oh, yes it can," said the owner of the shop; "I can make a sewing machine myself." "Well, you do it, Davis," said the other, "and I'll insure you an independent fortune." The emphatic assurance of the well-dressed, prosperous-looking speaker that a fortune was in store for the man who should invent a sewing machine greatly impressed the shy farm boy unused to city ways, who had already amused himself with inventing some slight improvements of appliances in the machine shop where he worked as an apprentice. There were other reasons, too, why such a trifling conversation should remain in his mind, for steady labor was not to his liking, and a kind of lameness which he had had since his birth frequently made his tasks painful.

He was not very proficient in his trade of machinist and not inclined to put forth much exertion. He was, however, of a thoughtful turn of mind and the conversation he had heard over the value of a sewing

machine set him to watching the process of sewing as performed by hand, and to wonder if there was a way to accomplish it by machinery.

This youth, Elias Howe, jr., born on his father's farm at Spencer, Mass., in 1819, had his attention directed at an early age to mechanics. There were a grist mill, a saw mill, and a shingle-cutting machine on the home place, but all of these and the farm together barely sufficed for the needs of the family of eight children.

When but 6 years old, Elias Howe worked with his brothers and sisters at sticking wire teeth into strips of leather to make cards used in the spinning of cotton. After "living out" for a year with a farmer in the neighborhood, he returned home to work in the mills there until he was 16. Then he obtained a learner's place in a factory in Lowell, Mass., making cotton machinery, until the financial panic of 1837 closed the shop and forced him to look for work again. Finally he found work in the shop of Ari Davis, an ingenious mechanic, where occurred the conversation already related.

When Howe was 21, and still a journeyman machinist, earning $9 a week, he married and before long there were three children to be fed and clothed out of his weekly wage. About the year 1843, the pressure of poverty and the fatiguing nature of his work, forced him to make earnest attempts to invent the machine which he had heard four years before would bring an independent fortune to the inventor. He wasted many precious months in endeavoring to copy the motions of his wife's arm when sewing, using a double-pointed needle with the eye in the middle. One day the idea came to him of using two threads and forming a stitch with the aid of a shuttle. By October, 1844, he had constructed a model which convinced him that he had a machine which would really sew. At this time he set up a lathe and a few tools in the garret of his father's house at Cambridge, Mass., and brought his family to the house, giving up his job as journeyman mechanic. He had his invention worked out in his head but these ideas could only really be tested by the construction of an accurately working model of metal. He was desperately poor and could barely provide the necessities of life for his family.

The money needed to purchase the raw materials for a working model that would put into concrete form his mental picture of a wonderful machine seemed beyond his reach. His earnestness, however, convinced a friend and former schoolmate, George Fisher, then a coal and wood dealer in Cambridge, of the feasibility of his project, and a partnership was drawn up for bringing Howe's invention into use.

By its terms George Fisher was to board Elias Howe and his family while Elias was making the model of his machine in Fisher's garret as a workshop, was to provide money for material and tools to the extent of $500, and in return was to be the owner of one-half

of the patent if the machine proved patentable. In December, 1844, the Howe family moved into Fisher's house and the shop was set up in the small, low garret. With the idea of his machine clearly in his mind and undisturbed by the need of daily laboring elsewhere to feed his family, Howe worked steadily on during the winter and by April, 1845, had sewed a seam on his machine. In July of that year he sewed on his model machine all the seams of two suits of wool clothes, one suit for George Fisher and one for himself.

This pioneer of the millions of sewing machines made since July, 1845, after crossing the ocean many times, and having been used as an irrefutable witness in many courts, can now be seen in the United States National Museum, at Washington, D. C., where it has been deposited by the grandson of Elias Howe, jr.

When Howe had finished his machine he found that his next problem was to convince others that it could sew and do the work as well as that performed by hand. Accordingly, he took his little machine to the Quincy Hall Clothing Manufactory in Boston and offered to sew up any seam that might be brought to him. For two weeks he sat daily in one of the rooms demonstrating his invention and finally challenged five of the swiftest seamtresses in the establishment to sew a race with the machine. Ten seams of equal length were prepared for sewing, one each was given to the five girls and the other five to be laid by the machine. The umpire testified that the five girls were the fastest sewers that could be found and that they sewed as fast as they could; Howe's machine, however, finished the five seams a little sooner than the five girls finished their five, and the work done by the machine was declared to be the neatest and strongest. In spite of this and similar demonstrations no one gave Howe an order for a sewing machine. When pressed for reasons some said they were afraid it would ruin all the hand sewers by throwing them out of work, some objected because the machine would not make the whole garment, others said the cost of the machine was too high as a large shirt maker would have to have 30 or 40 of them. Howe was not discouraged by these objections and set about to get his invention patented. He again shut himself up in George Fisher's garret for three or four months to make another machine for deposit in the United States Patent Office, as the patent laws then required. Late in the summer of 1846, a beautiful model and the required papers were ready for the Patent Office, and Elias and George took them to Washington. This model, Howe's second machine, is also exhibited in the National Museum, alongside of his original machine. It is a better made machine and shows several changes in unimportant parts. As soon as the patent was issued on September 10, 1846, Howe and his partner returned to Cambridge.

Without the enthusiasm of the inventor or the love given by him to his brain child, George Fisher became thoroughly discouraged. He had boarded the inventor and his family for nearly two years, had furnished the money needed to purchase the tools and materials for making the two sewing machines, he had met the expense of obtaining the patent and the trip of Howe and himself to Washington, representing in all an outlay of practically $2,000. Since no orders had been received from either garment makers or tailors for machines, Fisher did not see the slightest probability of the machine becoming profitable and regarded his advances of cash as a dead loss.

Elias Howe moved back to his father's house and the partnership with Fisher was practically at an end. But the inventor did not lose faith and decided to try to induce manufacturers in England to take up his invention. With a loan from his father, a third machine was made which Elias' brother, Amasa B. Howe, took with him to London in the steerage of a sailing packet. After a number of discouragements he made the acquaintance of William Thomas in his shop in Cheapside. This man claimed to employ 5,000 persons in the manufacture of corsets, umbrellas, valises, and shoes, and after studying the machine agreed to buy it. According to terms of this very one-sided bargain, Amasa Howe sold to William Thomas for £250 the machine he had brought with him from America (the third machine built by Elias Howe), and the right to use as many more in his own business as he wished. William Thomas proposed further to engage the inventor to adapt his machine to the making of corsets at a salary of £3 a week, and agreed to furnish workshop, tools, and materials. There was also an understanding that Thomas was to patent the invention in England and was to pay Howe £3 for every machine sold under the English patent. Thomas did patent Howe's invention but instead of paying him the promised royalty he collected for himself a tribute on all the sewing machines made in England, or imported into England, during the life of his patent. Elias Howe later estimated that the investment of £250 yielded Thomas a profit of a million dollars.

Amasa Howe returned to Cambridge, Mass., with Thomas' offer which Elias Howe reluctantly accepted, as there seemed no prospect of the sewing machine attracting attention in America, and the £250 were absorbed immediately by the needs of his family.

The brothers set sail for London, February 5, 1847, cooking their own provisions in the steerage. Elias took with him his precious first machine and his patent papers. William Thomas provided, as agreed, a shop and tools and advanced the passage money for the wife and three children of Elias Howe to join him in England.

After eight months of hard work the inventor succeeded in adapting his machine to the requirements of Thomas' business when the latter

began to make working conditions intolerable for Howe. The American resented his treatment which resulted in William Thomas discharging Elias Howe from his employment. A stranger in London, with a sick wife and three small children to support and no employment in sight was the disheartening predicament in which Howe now found himself. Through a chance acquaintance, a coach maker named Charles Inglis, he hired a small room for a workshop and with a few borrowed tools began to build his fourth sewing machine. He soon saw that he must reduce expenses or leave his machine unfinished, and decided to send his family home while he could, trusting that the machine he was building would provide the means for him to follow them.

He was so poor that he had to pledge some of his clothing to obtain a few shillings necessary to hire a cab to take his sick wife to the ship on the stormy night of her departure. After three or four months of hard labor his machine was finished and he looked for a customer. Finally a man was found who offered £5 for the machine if he could have time in paying for it. Howe was obliged to accept the offer and took the man's note for £5. His friend Inglis found a purchaser for the note at £4. In order to pay up his debts and pay his expenses back to America, Howe pawned his precious first machine and the patent papers from the United States Patent Office. To save cartage he took his baggage to the ship in a handcart and again took passage in the steerage along with his friend Charles Inglis.

Elias Howe landed in New York in April, 1849, after an absence from America of two years, with but half a crown in his pocket. Nearly four years had passed since the finishing of his first sewing machine and the small piece of silver was all he had to show for his work on that invention. He and his friend went to a cheap emigrant boarding house and looked for work in the machine shops, which he fortunately soon found. When news reached him that his wife was dying of consumption he did not have the money for the journey to Cambridge, but with the help of $10 from his father he was able to reach his wife's bedside before she passed away. In spite of his natural gaiety of disposition he was greatly downcast and looked like a man who had passed through a long and severe illness. However, he was now among friends who looked after his children and he was soon at work again as a journeyman machinist at regular weekly wages.

It is seldom that a man who makes a great invention is able to educate the public into using it. Neither Elias Howe, nor his friend George Fisher, could succeed in selling a machine which cost from $200 to $300 to build, and upon which the tailors looked with contempt or dread. Howe found to his surprise upon returning home from his experiences in London, that the sewing machine had become celebrated, though his part in its invention appeared

to have been forgotten. Several ingenious mechanics who had seen the Howe machine, or who had read of a machine for sewing, had turned their attention to inventing in the same field and sewing machines were being carried around the country and exhibited as a curiosity. Several machines made in Boston had been sold to manufacturers and were daily in operation. Howe found that these machines all infringed his patent rights by using devices which he had combined and patented. Though he was very poor the thought of all the suffering he and his family had endured while trying to introduce his invention determined him not to submit while others robbed him of his rights, and he began to prepare for war against the infringers. The first step was to get back from England his precious first machine and his patent papers. During the summer of 1849, the $100 necessary to redeem them was raised and intrusted to a friend who was going to London. The machine and papers were located, redeemed from pawn and returned to Howe within a few months. Howe wrote to the infringers of his patent, warning them to stop their manufacture and offering to sell them licenses to continue the use of his devices. All but one seemed willing to accept his proposition but that one pursuaded the others to resist and Howe was was soon forced to return to the courts for redress. With his father's help he began a suit, but soon discovered that money was required beyond the means of a poor journeyman mechanic. He endeavored to arouse the interest of George Fisher, who was still the owner of a half interest in the patent, but Fisher had had enough of the sewing machine and would not advance any more money. He was willing to sell his half of the patent for what it had cost him up to that time, and Howe looked around for someone to buy out Fisher's interest.

In February, 1851, George S. Jackson, Daniel C. Johnson, and William E. Whiting became joint owners with Howe of his patent rights, and helped him to procure witnesses in the furtherance of numerous suits. The next year a Massachusetts man named George W. Bliss was persuaded to advance the money needed to carry on the suits for infringement. This was done as a speculation, but so weak was his faith that he required as security against loss a mortgage upon the farm of the elder Howe. Elias's long-suffering parent again came to his rescue and the deal was completed.

While the suits were being carried on, Elias Howe found time to again engage in making sewing machines. Near the end of 1850 he was in New York looking after the construction of 14 of his machines in a shop on Gold Street, near which he opened a small office. Several machines were sold to a bootmaker in Worcester, several others were operated by garment manufacturers on Broadway, and one of the machines was exhibited at the fair held in the Castle Garden in October, 1851.

The infringers of Howe's patent were men of small means and could not put up much fight, but in August, 1850, Howe crossed swords with a man capable of carrying on a much more vigorous warfare than they. This man was Isaac Merrit Singer.

ISAAC MERRIT SINGER

This part of our story also begins in a machine shop in Boston. Lerow & Blodgett had patented a sewing machine on October 2, 1849, the peculiar feature of which was that the shuttle was driven entirely around a circle at each stitch. It was in some ways an improvement on the Howe machine, but the circular movement of the shuttle took a twist out of the thread at every revolution and the machine was hard to keep in running order. Several of these machines had been brought for repairs to the shop of Orson C. Phelps in Boston, where in August, 1850, their operation was watched by Isaac M. Singer who had shortly before patented a wood-carving machine. With the experience of a practical machinist, Singer criticized the clumsy working of the sewing machine, and when Phelps asked him how the defects could be overcome, Singer promptly said: "Instead of the shuttle going around in a circle I would have it move to and fro in a straight line, and in place of the needle bar pushing a curved needle horizontally I would have a straight needle and make it work up and down this way." Phelps assured him that if he could make a practical sewing machine he would make more money from it than from his carving machine. A recent boiler explosion in New York City had wrecked the machine shop where Singer's carving machine was being built and his machine was utterly destroyed. He was without funds to rebuild it and absolute poverty stared him in the face. The remarks of Phelps set him thinking and after considering the matter overnight he became satisfied that he could make the thing work. The next day Singer showed Phelps and George B. Zieber, a machinist working in the shop, a rough sketch of the machine he proposed to build. It contained a table to support the cloth horizontally, instead of a feed bar from which it was suspended vertically as in the Blodgett machine, a vertical presser foot to hold the cloth down against the upward stroke of the needle, and an arm to hold the presser foot and vertical needle-holding bar in position over the table. The story continues as told by Mr. Singer himself in a statement made during the progress of some litigation in which he was at one time engaged.

I explained to them how the work was to be fed over the table and under the presser foot by a wheel having short pins on its periphery projecting through a slot in the table, so that the work would be automatically caught, fed, and freed from the pins, in place of attaching and detaching the work to and from the baster plate by hand as was necessary in the Blodgett machine.

Phelps and Zieber were satisfied that it would work. I had no money. Zieber offered $40 to build a model machine. Phelps offered his best endeavors to

carry out my plan and make the model in his shop; if successful we were to share equally. I worked at it day and night, sleeping but 3 or 4 hours a day out of the 24, and eating generally but once a day, as I knew I must make it for the $40 or not get it at all.

The machine was completed in 11 days. About 9 o'clock in the evening we got the parts together and tried it; it did not sew; the workmen exhausted with almost unremitting work, pronounced it a failure and left me one by one.

Zieber held the lamp, and I continued to try the machine, but anxiety and incessant work had made me nervous and I could not get tight stitches. Sick at heart, about midnight, we started for our hotel. On the way we sat down on a pile of boards, and Zieber mentioned that the loose loops of thread were on the upper side of the cloth. It flashed upon me that we had forgot to adjust the tension on the needle thread. We went back, adjusted the tension, tried the machine, sewed five stitches perfectly and the thread snapped, but that was enough. At 3 o'clock the next day the machine was finished. I took it to New York and employed Mr. Charles M. Keller to patent it. It was used as a model in the application for the patent, the extension of which is now asked.

Starting with a borrowed capital of $40, this poor mechanic found that he was pursuing a difficult road. Discouragements and disappointments met him at every turn. Persons who had bought sewing machines on the strength of inventors' statements had been obliged to throw them aside as useless, so every man who pretended to have a real practical machine was considered an imposter. Singer found to his sorrow that whoever attempted to bring out a sewing machine was confronted with all the consequences of previous failures.

Blodgett, whose rotary shuttle machine had been the means of directing Singer's inventive powers to the field of mechanical sewing, told Singer that he was a tailor by trade and knew more about sewing than Singer possibly could. He advised Singer to give up the attempt to manufacture sewing machines and sell territorial rights instead, since even though the Blodgett machine had been the leading one on the market he felt assured that "sewing machines would never come into use." Three factories which he had established to use his sewing machines had failed. In spite of this kind of advice from all sides, this undaunted mechanic struggled on, fighting poverty, determined to force the public to recognize the fact that a practical sewing machine had actually been made. He borrowed a few hundred dollars from friends to enable him to manufacture machines in Boston, where, with Phelps and Zieber, he began work under the firm name of I. M. Singer & Co. The firm was gaining the attention of the public, when a new and formidable obstacle appeared. The news that Singer had made a machine that would actually do *continuous* stitching, the most conspicuous defect in the Howe machine, soon brought Elias Howe, jr., to his door with a demand that he pay $25,000 for infringement of the Howe patent, or quit the sewing-machine business. It did not take long for a man who had recently borrowed $40 to start his business, to decline the payment of $25,000

tribute, but neither was Singer disposed to give up his hard-won advantage without a fight. He soon found himself burdened with litigation which threatened to ruin him. About this time Singer secured the help of an acute legal mind in the person of Edward Clark, of New York, whose ability as a financier was hardly less marked. Although he contributed no money, Clark became an equal partner in the firm of I. M. Singer & Co., Phelps having been bought out some time before. Later Singer and Clark bought out Zieber.

Singer's success in developing a practical machine had encouraged other inventors and a number of other machines were brought out, some of them only obvious attempts at slight improvements on the Howe machine, but a number were fundamental inventions of a new type. Howe's patent of 1846, for the time being, made him a complete master of the situation and for several years he sued infringers right and left. The sewing-machine manufacturers, with the exception of the Singer Company, yielded to Howe and were carrying on their business under his licenses without interruption. I. M. Singer & Co. had resisted him single-handed from the very beginning, setting up in justification of their right to manufacture sewing machines, the claims of Walter Hunt, the New York inventor, that he had made a sewing machine, using an eye-pointed needle and a shuttle to form the lock stitch, previous to the year 1834. As Walter Hunt was unable to produce a complete machine made at that time and admitted that he had failed to apply for a patent on his invention, the courts decided that it was never completed in the sense of the patent law and therefore did not anticipate the patent granted to Howe. I. M. Singer & Co. submitted to the order of the court, for much damage was being done to their business by the competition of manufacturers who were working uninterruptedly under licenses from Howe, and in July, 1854, took out a license under the Howe patent, paying him $15,000 in settlement for royalties on machines made and sold prior to that time.

The decision of the court sustaining Howe's claims was made nine years after the completion of his first machine, and after eight years of the first term of his patent had expired. The patent, however, had been so little productive of revenue that Howe was able, in spite of the cost of the numerous suits for infringement he had started, upon the the death of his partner, George Bliss, to buy his half interest, and thus became, for the first time, the sole owner of his patent. This occurred just when it was about to yield an enormous revenue. His success in his suit against the Singer Co. made it easy to enforce his legal rights against others. In 1860 he obtained an extension of his patent for seven years, and though he again applied for another extension in 1867, claiming that he had received only $1,185,000, and that because of its value to the public he should receive at least $150,000,000, his second extension of the patent was denied.

The copartnership of Singer and Clark was continued until 1863, when a corporation was formed to continue the business. Singer withdrew from active work, receiving 40 per cent of the stock of the new company, and left America to make his home in Europe. Upon his death, 12 years later, his estate was appraised at $13,000,000.

Singer's original patent model is preserved in the National Museum. This type of machine, in use for many years, required less modification than any one of the earlier makes of sewing machines.

Isaac Singer was the first to furnish the people with a successfully operating and practical sewing machine. After the introduction of the Singer machine other inventors, with patents of earlier date, were forced to alter their machines to meet the approval of the public.

ALLEN BENJAMIN WILSON

One of the ablest of the early inventors in the field of mechanical sewing, and by far the most original, was Allen B. Wilson. This ingenious young man completed a practical sewing machine early in the year 1849 without ever having seen one and without having any knowledge of the work of Elias Howe, who was then in London.

In 1847, Allen Wilson, at 20 years of age, was working as a journeyman cabinetmaker in Adrian, Mich., far removed from any possible contact with the sewing-machine inventors of New England, when the idea first came to him of making a machine to sew. In a letter to a friend he describes his poverty at this time and the difficulties under which he worked. "I was in needy circumstances, earning but little more than enough to board and clothe me. I was taken sick early in the spring of 1847, with fever and ague, which greatly reduced me; I have never fully recovered from it."

Wilson had first begun the development of a needle and shuttle machine, but instead of using a shuttle pointed at one end and moving back and forth in a straight line, as had both Howe and Singer, he made a shuttle pointed at both ends and which moved in a curved path, forming a stitch at each forward and backward stroke. Before he had been granted this patent he was threatened with a lawsuit by the unscrupulous owners of an interest in another machine having a 2-pointed shuttle, unless he would convey to them half his interest in his patent when issued. Having no money to defend his right, and his partner, Mr. Chapin, being unwilling to advance any more, he consented to a compromise. About this time Allen Wilson made the acquaintance of Nathaniel Wheeler, a manufacturer of buckles and other small metal wares at Watertown, Conn. Mr. Wheeler saw Wilson's sewing machine in New York City, and made a contract with the firm controlling the patent to build 500 machines for them. He also engaged Wilson to go with him to Watertown to perfect the machine and superintend its manufacture. In the meantime, Allen

Wilson had thought out the plan of a substitute for the shuttle, the rotary hook, a marvelous piece of ingenuity. He showed Mr. Wheeler his model, who became so convinced of its merits that he determined to develop the new machine and leave Wilson's first shuttle machine to those who, by fraud, had become the owners of it. This last firm possessed neither the mechanical nor business ability to put it properly on the market, and in a few years the original patent was purchased by the Wheeler & Wilson Manufacturing Co.

Wilson now bent all his efforts to improving his rotary hook which was a new departure from all previous ideas of sewing, and was described in his second patent, issued on August 12, 1851. It is a remarkable coincidence that on the same date a patent was granted to Isaac M. Singer for his first machine, which, with its improvements, was for many years the most formidable competitor of the Wheeler & Wilson machine.

Wheeler, Wilson & Co. at once began the manufacture of the new machines. The sewing machines which had been previously patented and sold to the public were so difficult to operate and so impracticable that there was much distrust of all such devices and but few were willing to even try them. With the assistance of his wife to operate the machine, Wilson demonstrated to O. E. Winchester, later the head of the Winchester Repeating Arms Co., but at that time a large manufacturer of shirts in New Haven, Conn., its ability to neatly and rapidly make a shirt. Mr. Winchester was so agreeably surprised with the quality of the work that he agreed to take some machines on trial. In the same way machines were left for trial in Troy, N. Y., Boston, and Philadelphia. Soon the business was on a substantial basis and in October, 1853, a stock company was formed under the name of the Wheeler & Wilson Manufacturing Co.

Wilson's fourth patent, the universally used 4-motion feed, was issued on December 19, 1854. This, with the rotary hook and the stationary circular disk bobbin, the subjects of his second and third patents in 1851 and 1852, completed the essential features of Wilson's machine, original and fundamentally different from all other machines known at that time.

The first crude models, whittled out of mahogany by Allen B. Wilson between 1847 and 1849, which clearly show the development of his ideas, and the original models deposited in the Patent Office establishing the claims made in his first three patents, are now preserved in the National Museum. The model representing the third patent, that of June 15, 1852, is a beautifully made, compact little machine, weighing but 6½ pounds, and contrasting greatly with the clumsy, heavy Singer models of that time which weigh over 55 pounds.

Having applied his inventive genius to starting the business, Mr. Wilson was at his own request, upon the reorganization of the firm

in 1853, released from active service or further responsibility for the company. His ill health, and the effects of his early struggles and a keenly sensitive nervous temperament made it desirable for him to be relieved of the daily routine of the business. During his leisure he found time to explore other fields of invention, among which were cotton-picking machines, photography, and illuminating gases.

Wilson did not receive a proper reward for his great inventions, especially when this is compared with the earnings of Howe and Singer, whose inventions were mechanically much inferior. In his petition to Congress in 1874 for a second extension of his three patents, he stated that he had not received more than his expenses during the 14-year term of his original patent and that because of his poverty he had been compelled to sell a half interest in his patent for $200. He also stated that for the 7-year term of the extension of his patent he had only received $137,000. These statements were verified by his original partner.

JAMES EDWARD ALLEN GIBBS

The invention of the first practical single chain-stitch sewing machine came about through the curiosity of a young native Virginian having a mechanical turn of mind. James Gibbs had been helping his father build wool-carding machines, but the burning of his father's mill and the competition of large factories led him to turn to carpentering to provide for his family. It was in 1855 that his attention was first attracted to sewing machines by seeing a plain woodcut of a Grover and Baker machine in a newspaper advertisement. This picture showed only the upper part of the machine which left the course of the needle and the manipulation of the thread under the cloth a mystery. There was nothing in the cut to show that more than one thread was used and it at once excited his curiosity to know how the thing could possibly sew. His effort to solve the puzzle is best told in his own words:

> As I was then living in a very out of the way place, far from railroads and public conveyances of all kinds, modern improvements seldom reached our locality, and not being likely to have my curiosity satisfied otherwise, I set to work to see what I could learn from the woodcut, which was not accompanied by any description. I first discovered that the needle was attached to a needle arm, and consequently could not pass entirely through the material, but must retreat through the same hole by which it entered. From this I saw that I could not make a stitch similar to handwork, but must have some other mode of fastening the thread on the underside, and among other possible methods of doing this, the chain stitch occurred to me as a likely means of accomplishing the end. I next endeavored to discover how this stitch was or could be made, and from the woodcut I saw that the driving shaft which had the driving wheel on the outer end, passed along under the cloth plate of the machine. I knew that the mechanism which made the stitch must be connected with and actuated by this driving shaft. After studying the position and relations of the needle and shaft with each other, I conceived the idea of the

revolving hook on the end of the shaft, which might take hold of the thread and manipulate it into a chain stitch. My ideas were, of course, very crude and indefinite, but it will be seen that I then had the correct conception of the invention afterwards embodied in my machine.

Having no further interest in view than to satisfy his curiosity as to how sewing by machinery could be done he gave the matter no further attention or thought until January, 1856. Then while on a visit to his father in Rockbridge County, Va., he happened to go into a tailor's shop where there was a Singer sewing machine working on the shuttle principle. He was much impressed with the ability of that machine, but thought it entirely too heavy, complicated, and cumbersome, and also that the price was exorbitant. He then set to work in earnest to produce a more simple, cheap, and useful machine. His family was dependent upon his daily labor for support, so that Gibbs had very little time to spare for experiments, and could work on his invention only at nights and in bad weather. He was at a great disadvantage for want of tools and materials, having to make his own needles and parts of wood. By the end of April, 1856, he had so far completed his model as to interest his employers in his invention and induce them to furnish the money necessary to patent it and develop the machine. Gibbs then came to Washington, where he examined the models in the Patent Office and some of the sewing machines then on the market. He took his machine to Philadelphia and showed it to James Willcox, who was then engaged in building models of new inventions. Mr. Willcox and his son Charles were favorably impressed with the invention and it was arranged that Gibbs and Charles Willcox should work together in developing any possible improvements, using for this purpose a small room in rear of the shop. After taking out some minor patents he obtained his most important one on June 2, 1857. The original models of these early efforts are preserved in the National Museum. This association with James Willcox led to the formation of the Willcox & Gibbs Sewing Machine Co., which has certainly done its share in the development of the sewing machine art.

During the Civil War, Gibbs was in sympathy with the South, while his partner Willcox supported the North. Owing to poor health, Gibbs took no active part in the fighting, occupying himself in the manufacture of saltpeter for gunpowder. At the close of the war he called on James Willcox at Philadelphia and was shown by his faithful partner that his interests had not suffered during his absence.

Raised among the hills of the Shenandoah Valley, James E. A. Gibbs never forgot his love for Virginia and after he became prosperous, he bought a farm in his native county, where he lived the latter part of his life.

WILLIAM O. GROVER

Something of the origin of another and still different type of sewing machine which was developed about the time of the Wilson and Singer machines forms a necessary part of our story. This was the double-locked chain-stitch machine invented by William O. Grover, a Boston tailor. Though the machines which he had seen were not very practical he came to the conclusion that the sewing machine was going to revolutionize the tailoring trade, and in 1849 began to experiment with the idea of making an improved stitch. One plan was to invent a machine which would take its thread directly from the spools and do away with the need of rewinding the under thread upon bobbins. After a great deal of experimenting he finally discovered that two pieces of cloth could be united by two threads interlocking with each other in a succession of slip knots, but the building of a machine to do this proved to be a very difficult task. It is remarkable that during his experiments he did not discover the single thread chain stitch, later worked out by Gibbs, as up to this time this stitch had not been heard of by any sewing-machine inventors in America. It is probable that, working on the assumption that it was absolutely necessary to use two threads, the idea of using one thread could not find room to develop in his brain.

Grover's patent was issued, February 11, 1851, and the original model is shown in the collection of sewing machines in the National Museum. Mr. Grover associated with himself in the development of the business another Boston tailor, William E. Baker, and upon a reorganization of the company soon after under the name of the Grover & Baker Sewing Machine Co., took into the firm Jacob Weatherill, mechanic, and Orlando B. Potter, lawyer. This company built in Boston a most complete factory for the production of the machines. Mr. Potter, the president of the company, had, through his ability as an attorney, secured a one-third interest in the business without an investment at the start, and now obtained patents for Grover's inventions and managed all the lawsuits brought against the company. He was the promoter of the first trust of any prominence formed anywhere. It was known as the "sewing-machine trust," or more popularly, the "combination."

THE SEWING MACHINE COMBINATION

The celebrated suit between Elias Howe, jr., and I. M. Singer & Co., was decided by Judge Sprague of Massachusetts in the year 1854, a verdict being rendered in favor of Howe. This verdict was of the greatest importance, for it covered the use of an eye-pointed needle in a sewing machine. Howe's success in the suit against Singer was followed soon after by a verdict against the Wheeler & Wilson Co.,

Grover & Baker Co., and other infringers of Howe's patent. These decisions put Howe in absolute control of the sewing-machine business and he made arrangements with the various companies to pay him $25 for every machine sold. From this enormous royalty he derived a large revenue for some time. However, Howe did not have entirely easy sailing, and more legal battles took place. While none of the other inventors' machines could sew without using the eye-pointed needle, patented by Howe, the latter's machines were in many ways so badly handicapped, especially by his slow and clumsy method of feeding the cloth, that they were of no practical use. When he attempted to improve his machine so as to overcome these defects, Howe got into further litigation with I. M. Singer & Co., the Wheeler & Wilson Co., and the Grover & Baker Co., for infringing mechanical patents which were owned by them. The quarrels over patent rights were by no means confined to Howe, as each individual company was suing all of the others on one claim or another. Finally, Orlando B. Potter, president of the Grover & Baker Co., conceived the idea of combining the various interests and pooling all the patents covering the essential features, which would enable them to control the sewing-machine industry, instead of continually fighting and trying to devour one another. He pointed out that while Howe and the three large companies then suing one another controlled all the basic patents, the pending lawsuits if carried to a conclusion, might be disastrous to all of them. His argument was convincing and thus was formed the "combination" which for several years was the terror of all unlicensed manufacturers. Besides Howe, the three companies which were parties to the combination, I. M. Singer & Co., the Wheeler & Wilson Co., and the Grover & Baker Co., had all begun business about the same time, and the main patents under which they were working had been granted between November 12, 1850, and August 12, 1851.

At first Howe did not take very kindly to the idea of the combination as he felt that he had the most to lose by joining it. He insisted as one of the conditions of his coming into the plan that at least 24 licenses to manufacture sewing machines be issued. By the terms of the agreement he was to share equally with the other three parties in the profits of the combination, and in addition was to receive a royalty of $5 for each machine sold in the United States, and $1 for each machine exported.

It is estimated that Howe received in the form of royalties as the result of this agreement not less than $2,000,000 from the business of the combination.

The three other concerns contributed their various patents to the combination, and the price for a license to manufacture was set at $15 per machine, with the condition that no license could be

granted without the consent of all four parties. It was also agreed that a portion of the license fees was to be reserved as a fund out of which to pay the cost of prosecuting infringers.

This arrangement enabled manufacturers to continue making machines by the payment of only one license fee to the combination, and anyone who had a good machine that was not an offensive imitation of that of some other licensed manufacturer was granted a license. There was no pooling of any other interest in the combination excepting that of patents; each company retained the right to make a certain machine and aimed to so improve and perfect its own particular machine that it would be selected instead of others.

The most important patents contributed to the combination were the following:

1. The combination of the grooved, eye-pointed needle and a shuttle, by Elias Howe, jr.
2. The 4-motion feeding mechanism, by Allen B. Wilson.
3. The continuous wheel feed, the yielding presser foot, and the heart-shaped cam as applied to moving the needle bar, by Isaac M. Singer.
4. The basic patent covering a needle moving vertically above a horizontal work plate, a yielding presser resting on the work, and a "perpetual" or continuous feeding device, which had been issued to John Bachelder on May 8, 1849, and afterwards purchased by Singer and his partner Clark.

The Grover & Baker Co., controlled several patents of importance which were contributed to the combination, but its most important claim for admission was the fact that Mr. Potter had promoted the scheme.

When Howe's patent was renewed in 1860 the general license fee was reduced from $15 to $7, and Howe's special royalty from $5 to $1.

The combination continued in existence with Howe as a member until the expiration of the extended term of his patent in 1867, and was then continued by the other members until 1877, when the John Bachelder patent expired. This patent had been twice extended, so that it ran for 28 years. The fundamental principles of the sewing machine were now no longer controlled by any one, the beneficial open competition of the smaller manufacturers was made possible, and an enormous reduction of prices resulted. Many important and radical improvements appeared in quick succession, which greatly multiplied the usefulness of the sewing machine.

CONTRIBUTIONS OF THE PIONEER INVENTORS

Leaving for the time these accounts of the struggles of pioneer inventors in the field of mechanical sewing to prove the practicability of their ideas, let us see what were the real achievements of these men. While the drawings of Saint's sewing machine, which was patented in England in 1790, show the overhanging arm, the up and down movement of the needle, the horizontal bed or plate to support the

sewing, and a continuous thread, it is doubtful if any but the experimental machine was ever made, so that nothing was done by this inventor toward making his invention useful to mankind.

To Barthelemy Thimonnier, however, belongs the credit for having been the first to put the sewing machine to practical and public use. While his machine, patented in France in 1830, adopted some of the features of Saint's machine, Thimonnier put his machine to a practical and useful purpose, and had it not been for the opposition of the very class of people who have since been benefited by it he would undoubtedly have found profit in the enterprise.

To Walter Hunt belongs the honor of having invented the needle with the eye in the point and having first combined the shuttle and the eye-pointed needle to make the lock stitch; and this was as early as 1832, or shortly thereafter, while Thimonnier had only just succeeded in sewing with a machine, nor can this honor be taken away from Hunt because he neglected to pursue his invention and introduce the sewing machine to the world.

To Elias Howe must be given the credit for the first introduction of the sewing machine to the prominent position which it now occupies. There is no denying the fact that it was due to his persistency that most of the principles of good sewing were demonstrated by his patent. As one writer has expressed it: "With inventive abilities inferior to those of Walter Hunt he (Howe) had an adaptness to follow out a single object persistently, and he reaped the field." The combination of an eye-pointed needle and shuttle using two continuous threads to produce a lock stitch was a feature of the embroidering machine invented by John Fisher in England in 1844, but the English had never improved upon the idea nor had even applied it to a machine to do ordinary sewing prior to the sale of Howe's third machine to William Thomas for use in his corset factory. Although the eye-pointed needle was invented by Hunt and used by him in 1834, and was patented in England in 1841 as part of a glove-stitching machine using the chain stitch, nevertheless Howe's machine was the first to be patented anywhere having a needle with the eye in the point which carried a continuous thread and made a lock stitch.

Howe's machine was capable of sewing a seam well but it must be admitted that the machine was far from perfect. As constructed it could never have come into use as a labor-saving machine for family use, for it could not sew anything but straight seams, and such seams could not be longer than the baster plate.

Of all the pioneers of sewing machine invention Allen B. Wilson was decidedly the most original in his ideas. His devices were unique and lasting in their usefulness. No sewing-machine device except the eye in the point of the needle has come into such universal use as his 4-motion roughened-surface feed. The vast majority of the sew-

ing machines made in the world to-day use the 4-motion feed. It was one of the strongest patents of those held by the famous sewing machine combination, and enabled that famous monopoly to defy all comers until its expiration.

When Wilson found that the idea of a double-pointed shuttle, although original with him and used in his first patent, was claimed by the owners of a patent granted to John A. Bradshaw in 1848, he applied his inventive genius to discover another way to sew. These efforts resulted in the development of the revolving hook for forming a lock stitch between an upper and a lower thread, an invention involving the use of entirely different mechanical principles. While the shuttle system of sewing has been arranged and changed in a thousand different ways, the revolving hook system remains in principle the same as Allen B. Wilson devised and left it. He not only contributed to the history of the sewing machine one of the most important devices common to all systems of machine sewing, but he was the author of a separate and entirely original system of his own.

A proof of the fundamental importance of Wilson's contributions is seen by the fact that a sewing machine embodying the form and principles used in the first type of machine manufactured by the Wheeler & Wilson Co. in 1852 is made and used by its successor to-day—77 years later.

To Isaac Singer should be given the credit for developing the first real practical sewing machine for domestic use. While the yielding vertical presser foot to hold the work on the work table, which is in universal use to-day, and the development of the wheel feed, an important feature of some special machines for factory use, were contributed by Singer in his first machine, his real service was in bringing the sewing machine into general use. When the competition of Singer's machine began to be felt, inventors of machines of an earlier date were compelled to modify their inventions and adapt them to meet practical conditions and to please the public. Later Singer himself was compelled to do the same thing and changed materially the heavy cumbersome form of his earlier type to meet the competition of the smaller, lighter, and easier running Wheeler & Wilson machine.

The principles of William Grover's double-thread chain-stitch machine, while no longer used in the present-day sewing machines built for domestic sewing, are very extensively employed in the machines built for all kinds of manufacturing purposes, especially those for making underwear, garments, sewing bags, and shoes.

THE SEWING MACHINE IN THE EARLY DAYS

The early efforts to construct a machine to take the place of the human arm and fingers were met with the indifference of the general public, but certain groups of workers with the needle saw in these

inventions a menace to their crafts, and endeavored to destroy them wherever they appeared. Another portion of the public was amused at the claims made for the freak "Yankee" machines and were curious enough to pay good money to see the "contraptions" exhibited in side shows.

One of Barthelemy Thimonnier's wooden machines was sent by him from France to his friend Charles Magnin in England to be shown at the Crystal Palace Exhibition held in London in 1851. It was exhibited by Magnin in his own name and received no notice whatever. There were exhibited at the Crystal Palace at the same time several English so-called sewing machines and one American machine, which had been patented by Morey and Johnson of Boston on February 6, 1849. While no notice was taken by English writers on science or technology of the few clumsy instruments catalogued as sewing machines which were shown at the "great exhibition of the world's industry," these machines did attract the attention of an astonished reporter for an important Italian newspaper. The following paragraph is a translation from an article in the Giornale di Roma, giving its readers a brief summary of American eccentricities in the Crystal Palace:

> A little further on you stop before a small brass machine, about the size of a quart bottle; you fancy it is a meat roaster; not at all. Ha! ha! It is a tailor! Yes, a veritable *stitcher*. Present a piece of cloth to it; suddenly it becomes agitated, it twists about, screams audibly—a pair of scissors are projected forth—the cloth is cut; a needle set to work, and lo and behold, the process of sewing goes on with feverish activity, and before you have taken three steps a pair of *inexpressibles* are thrown down at your feet, and the impatient machine, all fretting and fuming, seems to expect a second piece of cloth at your hands. Take care, however, as you pass along, that this most industrious of all possible machines does not lay hold of your cloak or greatcoat; if it touches even the hem of the garment it is enough—it is appropriated, the scissors are whipped out, and with its accustomed intelligence the machine sets to work, and in a twinkling another pair is produced of that article of attire, for which the English have as yet been able to discover no name in their most comprehensive vocabulary.

In the United States in the meantime more serious attention was being paid to the new inventions which promised so well to lessen the labor of the needleworkers. The early issues of the Scientific American devoted considerable space to a description of each new sewing machine that appeared. From the issue of July 17, 1852, which told of the achievements of Allen B. Wilson, the following prophecy is quoted:

> * * * When we look at the progress made in sewing machines, we expect them to create a social revolution, for a good housewife will sew a fine shirt, doing all the seams in fine stitching, by one of Wilson's little machines in a single hour. The time thus saved to wives, tailors, and seamstresses of every description is of incalculable importance, for it will allow them to devote their attention to other things, during the time which used to be taken up with dull seam sewing. Young ladies will have more time to devote to ornamental work (it

would be better for them all if they did more of it), and families in which there are a number of children, which require a continual stitching, stitching, in making and mending from morning till night, will yet be blessed by the improved sewing machine.

The sewing machine is but on the threshold of its career; it is but partially known and applied in our country. Private families know nothing about its use, and shoemakers and saddlers have not yet tested its benefits. Mr. Wilson informs us that he is about to make one that will sew boots and shoes with a rapidity that will astonish all the sons of St. Crispin. We suppose that, in a few years, we shall all be wearing shirts, coats, boots, and shoes—the whole habiliments of the genus homo—stitched and completed by the sewing machine. We suppose there are now fully 200 sewing machines in operation in New York City.

CHANGING CONDITIONS OF LATER TIMES

The effects on the economic life of the people and changes wrought in the home due largely to the invention and development of the sewing machine have been the theme of many addresses. The following quotation from an address made by Robert S. Taylor before the Patent Centennial Celebration in Washington, April 10, 1891, will serve as an example:

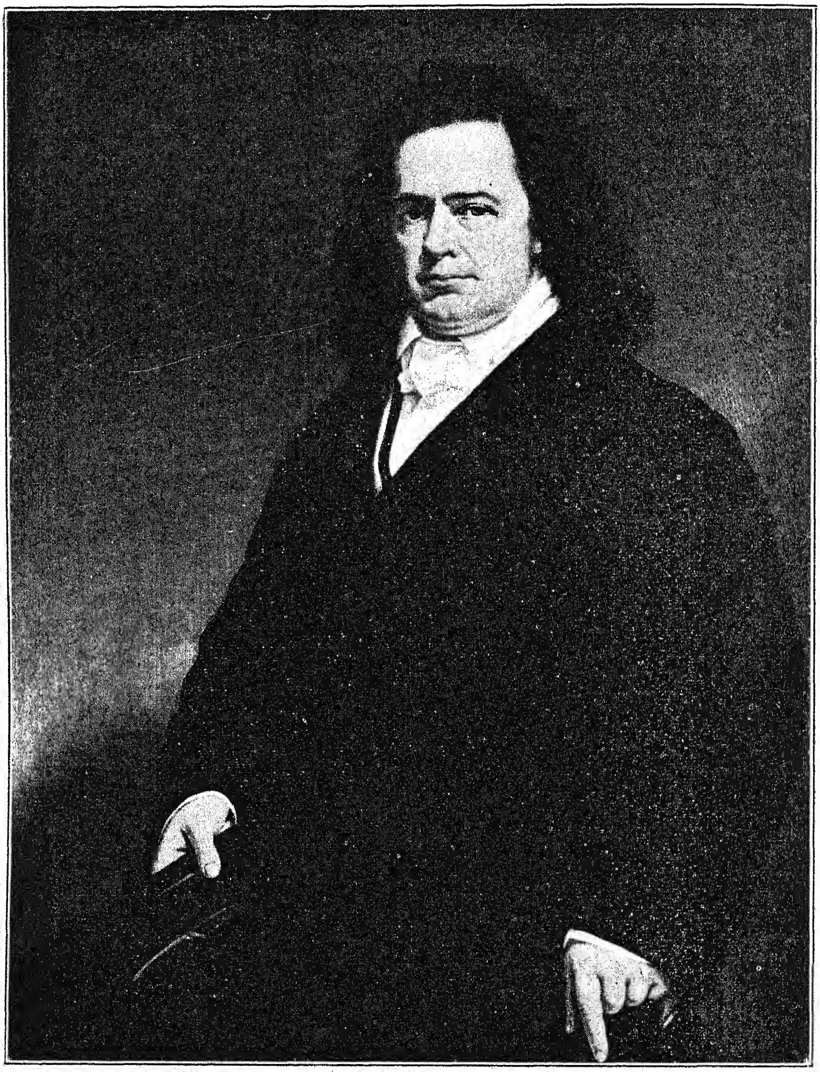
> It is too soon yet to estimate the full effect of the sewing machine upon human life and destiny. It ushered in an epoch of cheap clothes, which means better clothes for the masses, more warmth, more cleanliness, more comfort. * * * The indirect consequences of the invention of the sewing machine reach farthest beyond our ken. Time was when half the human race were occupied chiefly in making clothes. When the machines took that avocation away from them they turned to other employments. The invasion of all occupations by women and the sweeping changes which have taken place in their relations to the law, society, and business can be ascribed in large measure to the sewing machine.

The report of the United States Centennial Commission of the International Exhibition held in Philadelphia, 1876, contains an exhaustive account of the development of the type of sewing machines used in the homes of the people, the family sewing machines. An article of the same scope was prepared for the committee on awards of the World's Columbian Exposition, held in Chicago, 1893. In this but little is said concerning improvements made in machines of the family type between 1876 and 1893, but it describes the great strides made in developing factory machines for special purposes.

In spite of the widespread equipping of American homes with electric labor-saving devices, which now include the electrically driven sewing machine, the removal of so many domestic industries from homes to factories is having its effect on this "servant in the house."

WALTER HUNT

Photographed from a daguerreotype in the possession of his great-grandson, Clinton N. Hunt.

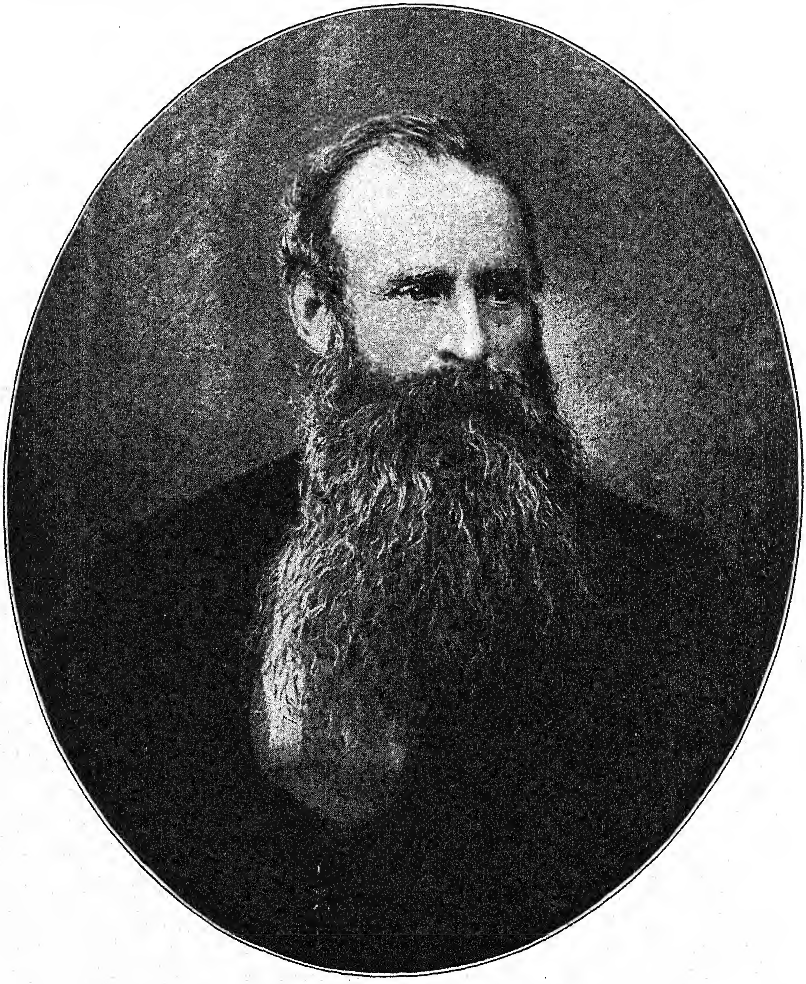


ELIAS HOWE, JR.

Photographed from the oil painting presented to the United States National Museum by his grandson, Elias Howe Stockwell.

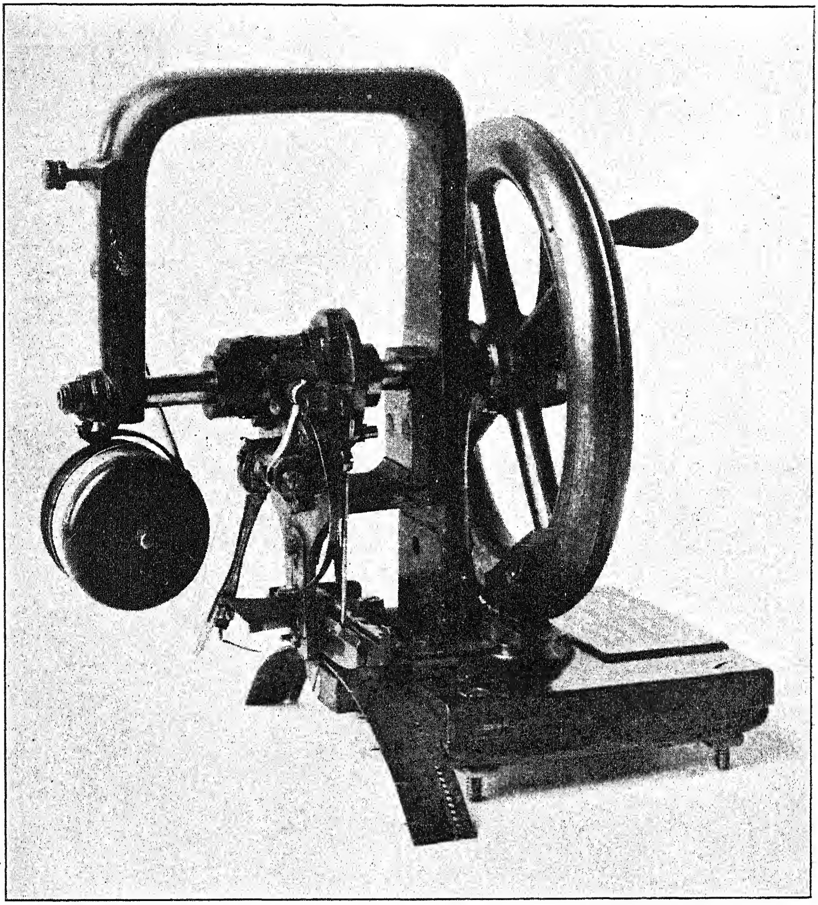
ISAAC MERRIT SINGER

Photographed from a charcoal drawing in the offices of the Singer Manufacturing Co., Elizabethport, N. J.



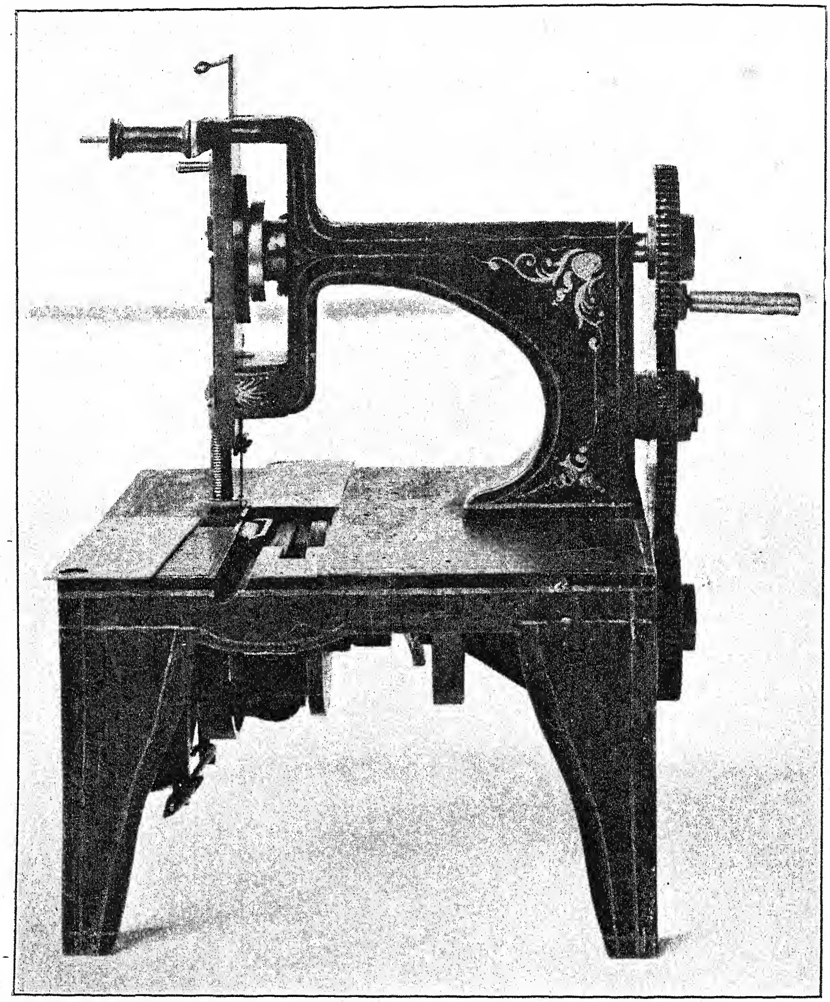
ALLEN BENJAMIN WILSON

Photographed from a drawing in the offices of the Singer Manufacturing Co., Bridgeport, Conn.; formerly owned by the Wheeler & Wilson Mamufacturing Co.



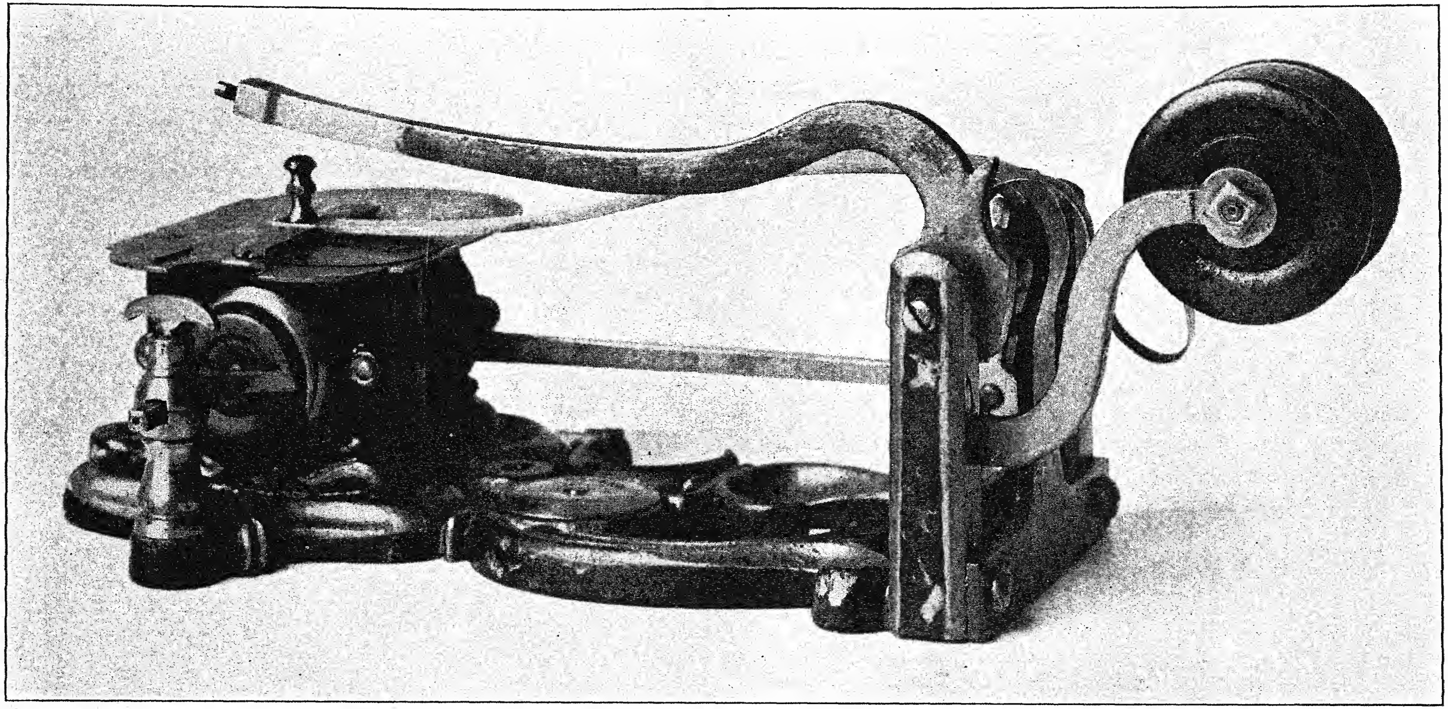
ORIGINAL SEWING MACHINE

Made by Elias Howe, jr., in 1845, and taken by him to England to interest manufacturers in his invention.



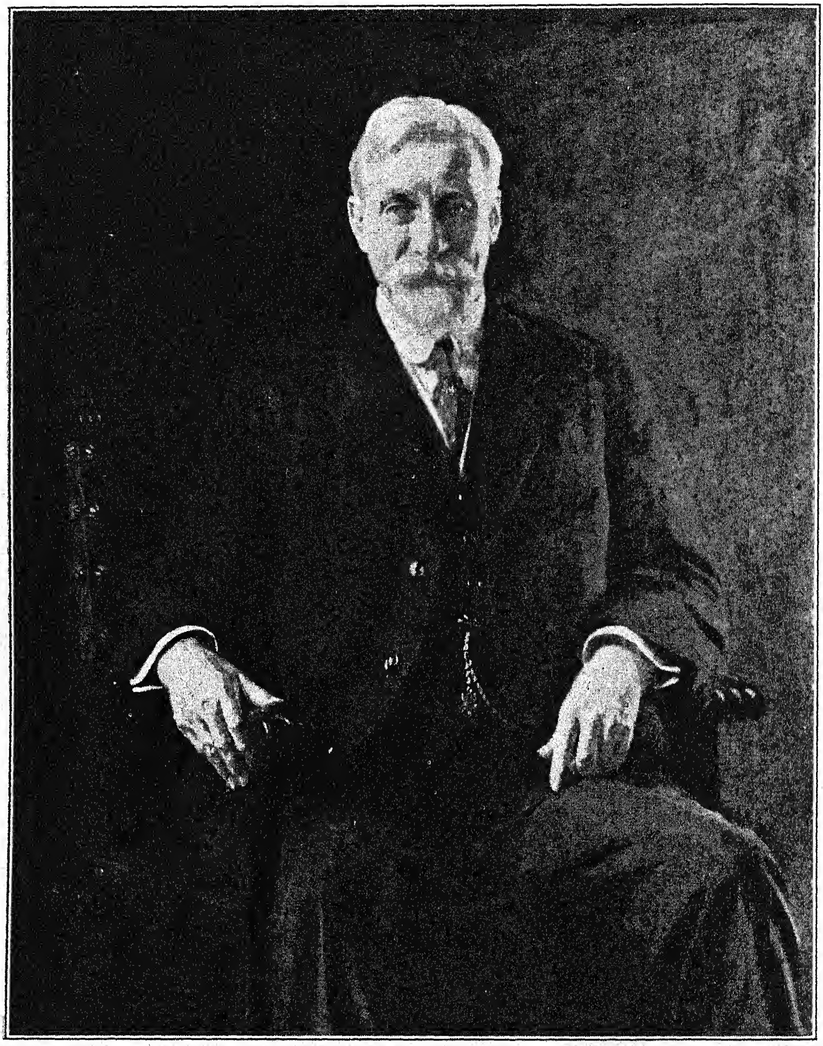
ORIGINAL MODEL OF UNITED STATES PATENT NO. 8294, ISSUED TO ISAAC M. SINGER, AUGUST 12, 1851

ILLUSTRATION OF SINGER SEWING MACHINE PUBLISHED IN 1853



ORIGINAL MODEL OF UNITED STATES PATENT NO. 9041, ISSUED TO ALLEN B. WILSON, JUNE 15, 1852

Wilson's third patent, embodying his famous 4-motion cloth-feeding device.



THOMAS CHROWDER CHAMBERLIN, 1843–1928

THOMAS CHROWDER CHAMBERLIN (1843–1928)[1]

By Bailey Willis

[With 1 plate]

Aristotle, 322 B. C.; Copernicus, 1543 A. D.; Galileo, 1642; Newton, 1727; Laplace, 1827; Darwin, 1882; Chamberlin, 1928.

The names of great original thinkers are milestones along the path of exploration that penetrates the domain of the unknown. Chamberlin's is the latest. He has led into new realms where for a while others will survey and establish monuments, but whence also another, some great follower of his example, will again strike out in search of knowledge.

He was a great master of research. Few among living investigators have demonstrated equal capacity for inquiry. Very few indeed have sustained equal flights of constructive imagination yet kept in touch with the realities. None, in preparing for such flights, has more thoroughly utilized the resources of advancing science or more rigorously tested the records of altitudes attained.

Chamberlin fortunately lived during an epoch when the sciences were growing vigorously. He kept abreast of them. He was no follower. Neither was he an egotistical leader. Cooperating closely with competent companions, he advanced always with strong support. In the group of coworkers his was the mind that conceived the campaign against misconceptions. His also was the ingenuity which suggested critical tests of every new concept. That leadership was his because of his superior capacities: Initiative, independence, and insight. Yet the least experienced of his company received considerate attention and generous appreciation for any valid contribution.

Born at Mattoon, Ill., September 25, 1843, Thomas Chrowder Chamberlin was 85 at his death, at Chicago, November 15, 1928. He was of large build, a vigorous, genial, generous personality.

From his father, who practiced farming during six days and preached biblical philosophy every seventh day, Thomas appears to have in-

[1] Reprinted by permission from Bulletin of the Geological Society of America, vol. 40, No. 1, March, 1929 Bibliography omitted.

herited his intellectual capacity. He himself said: "I was brought up in theological philosophy, but it was not Calvinistic predestination. Individuality, personality, responsibility are so strongly ingrained in me that I can not get rid of them." Evidently the father, like the son, was, within his own sphere, an independent, earnest, forceful thinker.

That he outgrew that restricted sphere of religious tradition, Chamberlin attributed largely to his environment as a boy. In a note on "little things" in his life he comments humorously on the fact that his birthplace was on the Shelbyville moraine, an intimation of his future interest in glaciation. More seriously he describes the influence of all outdoors upon the growing farmer's boy.

The most fascinating things of those days—to a boy of naturalistic bent—were the migrations of the birds, the spring migration in particular. The prairies were usually burnt over in the fall and so were often black and bleak during winter when not covered with snow, but as the spring advanced the grass began to make them grey and green, the buttercups and violets began to give them color, and then birds in uncounted flocks came from the south, fed upon them, and passed on. Blackness and bleakness gave place to color and life. No poor soul born in these days of plowed fields and wire fences ever sees sights like those.

A limestone quarry, which he worked with his brothers for stone for the house that replaced an older log cabin, introduced the boy to rocks and also to "snails" and "snakes" ("Trenton" fossils). Having been taught Genesis in its most literal terms, he found in these vestiges of creation no questions except as to how the great snakes (orthoceratites) got down between the layers.

To the prairie "the skies came down equally on all sides" and the boy lived in the center. He watched the northern lights and looked for shootings stars. He grew alert, but not yet inquisitive or inquisitorial.

In strong contrast with the untrammeled outlook of his natural environment, was the limited scholasticism of his school training. Chamberlin's reaction was characteristic. When still a college boy, but taking his first examination for a teacher's certificate, he encountered the gymnastic problem: "If the third of 6 is 3, what would the fourth of 20 be?" The desired answer might have been an arithmetical calculation which would have shown that a fourth of 20 is 7½, but the young student at once refused the fallacy. He replied:

The fourth of 20 is 5 under any and all circumstances and is not affected by any erroneous supposition that may be made in respect to a third of 6.

Late in life he answered the question with a more explicit expression of his attitude toward false postulates, saying:

If the third of 6 is 3 and if the whole universe were running on that crazy basis what might be the crazy proportion of the fourth of 20?

His conviction was profound that the universe had not been created by a crazy creator, and his antagonism to "crazy" assumptions

became intensified as the years passed. He had little patience with "denatured" theories. He held that

The greatest genius is probably a genius for seeing the realities of things—all the essential realities of actual problems.

Chamberlin himself possessed that genius in very high degree and he developed it conscientiously, always endeavoring to make his analysis of the realities as complete as possible. He thus advanced, step by step, far beyond the range of less daring minds, and with some incurred the charge of being unduly speculative because they did not realize how clearly he saw the facts. But even though he himself strove to make a complete analysis, he welcomed suggestions cordially. Three weeks before he died he wrote a fellow geologist who had thought to strengthen a point in the two solar families: "I hasten to acknowledge your contribution." He scorned pettiness and was incapable of appropriating another's thought unacknowledged.

Chamberlin was a teacher. His progress from the position of principal of the Delavan High School (1866–1868) to the "settee" of natural sciences at the State Normal School at Whitewater (1869–1872), thence to the professorship of geology at Beloit (1873–1882), to Columbian University (1885–1887), and to Chicago University (1892–1919) was the natural evolution of a career of teaching for which he was peculiarly fitted. It was interrupted from 1887 to 1892 by his service as president of the University of Wisconsin. But the administrative office had little attraction for a mind that cared nothing for authority and was devoted to the acquisition and diffusion of knowledge. Once when tendered the directorship of the United States Geological Survey he responded that he had come to consider alternative views too habitually to act satisfactorily as an executive, who must often decide "yes" or "no" in doubtful cases.

The teacher and the investigator went hand in hand. The embryo of his thinking on geology is found in the suggestions of his environment as a boy. His intellectual force was inborn, but the work it was to do was determined by the puzzling and tantalizing, because unexplained, facts: "snails" and "snakes" in the rocks, the migration of birds, the aurora borealis, the stars, all outdoors. His reaction to the stimulus was characteristically demonstrated when he dismissed the formal classes of the Delavan High School on a throbbing spring day to "go out to see if we can find things in nature worth knowing and thinking about."

Entering into official relations as assistant geologist on the Wisconsin Survey (1873–1876), Chamberlin was not given one of the preferred districts containing iron or lead, but was assigned to the economically barren southeastern quarter of the State. The rocks were the well known Paleozoic strata and they were deeply covered by glacial drift. The bald simplicity of the apparent problems might well have

produced an intellectual chill, but Chamberlin's logical insight penetrated the superficial appearances and discovered the deeper question. Back of the drift phenomena was a mysterious cause of climatic change. To discover it became his main purpose, and the search conducted him through an investigation of the origin of the atmosphere to a theory of the evolution of the solar system.

Led by him with an intellectual leadership that has never been questioned, a group of able geologists has analyzed the drift sheets of North America, mapped their extent and detailed structure, and contributed a thorough understanding of the Pleistocene record. It is a great contribution. It demanded capacity for intimate and discriminating observation of differences where others saw sameness—for careful and alternative interpretation on the basis of process, stage, and environment, for balanced judgment and impartial testing of probabilities. It called for those qualities which Chamberlin already possessed to a high degree but which he was to train to even more difficult tasks.

As the complexity of the glacial periods became more evident, the enigma of the cause grew more impressive. No satisfactory solution had been proposed, as appeared on testing the current theories by the accumulating facts. None was possible under the accepted doctrine of atmospheric evolution from the steaming envelope of a molten globe to the present life-giving air. The enigma deepened and broadened as the eager but patient student searched not only geology but all allied sciences for clues.

He gives Tyndall credit for the suggestion that led him to consider the relation between climatic conditions and the constitution of the atmosphere. The proportion of carbonic acid appeared to be a critical factor. The variables involved in its variation were found by Chamberlin to link geological, chemical, and biological processes in cycles of mutual reactions. The antiquity of recurrent climatic changes turned the investigation back from the Pleistocene to the pre-Cambrian glaciations, and thus to the origin of the atmosphere.

The inquirer could not pause there. The atmosphere of a molten earth indeed suggested tremendous possibilities, but they were not compatible with the facts of terrestrial history, so far as we can read it. The progress of knowledge had pushed a possible molten state of the earth even further back into vague traditional stages of creation.

Contrary to all that he had been taught, Chamberlin found himself obliged to consider alternative hypotheses that might be consistent with a less spectacular evolution, and he was forced to examine critically the very foundations of the geologic faith of that day.

He described his early work on theories of the genesis of the earth as resembling the exploration of an old mine to find what of value was left in the outworked leads and to discover what promising veins

might have been overlooked. The exploration occupied a number of years, demanded infinite patience, suspension of judgment, critical acumen, continuous self-instruction in the related branches of physics, chemistry, and celestial mechanics. Only a disciplined mind, trained absolutely to subordinate self-opinion to fact could have sustained the effort. If the example of Darwin was not consciously recognized, it was nevertheless paralleled.

Chamberlin recognized that terrestrial evolution is a dynamic process. Energy and force are vital, matter and environment simply important. This is the physicist's view, more rarely the geologist's. The dynamics of the globe are planetary dynamics. This is the astronomer's field, the geologist's only in the sense that "astronomy is the foreign department of geology."

Chamberlin's exploration thus reached into the realms of physics and astronomy. His powers of inductive reasoning did not fail him there, but he was not prepared to apply the methods of higher mathematics to research, as is commonly done in those sciences. He required associates to aid in testing hypotheses.

It does not appear that his environment developed favorable associations prior to his entrance into the faculty of Chicago University (1892). While at Columbian he was occupied with the more strictly geologic problems of Pleistocene classification. His associates, Gilbert, Dutton, and other fellow geologists, thought in the narrower field of terrestrial processes, and he with them. He was one of a group of similar thinkers similarly equipped. At Chicago it was different. In that newly organized faculty were leaders in related sciences, and among the students there appeared from time to time competent aids eager to work with the master of research.

Two men stand out as Chamberlin's chief associates: Rollin D. Salisbury and Forest R. Moulton. In different fields each one contributed materially to his work. Salisbury, a student at Beloit, devoted himself loyally throughout his whole career to supporting Chamberlin. He worked with his chief in glacial geology, in the organization and conduct of the department of geology at Chicago, and in the editorial work on the Journal of Geology, which they founded. He collaborated in the preparation of their comprehensive Manual of Geology, of which he wrote important sections. He was more than a helpful assistant in innumerable subsidiary tasks of administration, and he ranked high as a teacher. It was for Chamberlin a great good fortune to have drawn to himself a spirit so loyal, a collaborator so competent, a fellow teacher so superior as Salisbury.

Moulton brought to the cooperation with Chamberlin the resources of a mathematician and an astronomer. He was much younger than Chamberlin, and during their association developed from a young instructor to a mature scientist. In their research the method of

multiple hypotheses controlled. Their objective was a tenable hypothesis of the origin of the planetary system. They examined all the hypotheses that occupied the field and devised many others, both comprehensive and subsidiary. Chamberlin's constructive mind grouped facts, originated explanations, suggested tests. He reasoned by "naturalistic logic." Moulton's analytical genius checked Chamberlin's concepts against the principles of celestial mechanics, and applied critical mathematical tests to the dynamical consequences. In their discussions each always maintained independence of judgment. When agreements were reached it was only on convincing proof.

Even so, agreement between Chamberlin and Moulton was not regarded by them as demonstration. An hypothesis was abandoned only when it was clearly inconsistent with known facts or laws. All hypotheses that withstood the tests of the realities were carried on as possible working material. Yet after 25 years of research only one hypothesis of planetary genesis, the planetesimal, survived.

The gaseous group of genetic hypotheses represented by the theory of Laplace failed because the kinetic energy of gases would not permit the assembling of the actual planets by gravitation, as postulated, and the observed moments of momentum of revolution could not have been attained. The meteoritic hypotheses failed similarly to withstand Moulton's incisive studies of their dynamical implications.

Having failed to find a solution of their problem in the general concepts relating to the movements and attractions of stellar bodies, Chamberlin and Moulton turned their attention to the specific peculiarities of the solar system, in the hope of finding in them a suggestion of the conditions to which they owed their evolution. The orderly arrangement of the planets nearly in a common plane of orbits, the distribution of masses, which contrasts extraordinarily with the distribution of moments of momentum, the directions of rotation of the planets, and many minor peculiarities were critically studied. They suggested that two bodies had been concerned in the birth of the planets from the sun—the sun itself and a visiting star. This hint was developed constructively by Chamberlin and mathematically by Moulton, until the possibilities of a dynamical encounter had been traversed and that which seemed best to suit the actual facts of the solar system had been isolated from the general possibilities. This conception and demonstration belong entirely to Chamberlin and Moulton; they constitute a great original contribution in the field of celestial mechanics.

Directing his attention specifically to the evolution of the earth Chamberlin postulated the eruption of its mass from the sun as a result of the enormous expulsive activities of the sun, stimulated by the attraction of the passing star. This concept he has described as "the soul of the planetesimal theory."

A mass of gas expelled from the pressure and temperature of the sun into the vacuum and cold of space presents dynamical problems which divide physicists. Would it assemble in response to its own gravitation and form a molten globe? or would it be dispersed by the kinetic energy of the gas? Chamberlin and Moulton approached the question as a sequel to their investigations of the Laplacian and related gaseous assemblages. They had demonstrated the inefficiency of gravitation and the effectiveness of kinetic dispersion. They were forced to recognize that the mass would become a swarm of minute solid bodies which would swing into orbits about the sun and would thus become "planetesimals." The real problem was to account for the fact that the planetesimals had assembled, that each swarm had become a planet.

The problem is not one which yields to mathematical analysis unless it be stripped of inherent complexities and simplified to suit an imaginary case. Chamberlin analyzed it logically. He grasped the complexity of cyclonic motion in the sun, the compressive action of the tidal effect, the dominance of the expulsive force, the drag effect upon the bolt, and the consequent resemblance of the mass to a rolling cloud. He reasoned the transformation of the billowing bolt into the orbital swarm, in consequence of the attraction of the passing star, the formation of a heavy core, and the gradual growth of the earth by the infall of planetesimals.

He first published these views in 1903–04 in reports to the Carnegie Institution of Washington on research in fundamental Problems of Geology. He embodied them in more popular form in the Origin of the Earth, 1916. It was characteristic that to the end of his life he continued to pursue studies designed to test, modify, or perfect theories of the origin of the earth, including the Planetesimal. In 1926 he said concerning the latter:

> For 25 years I have tested every hypothesis of the genesis of the earth of which I could learn or which I could conceive. One and one only has withstood every critical test. Do you think I am justified in thinking it probably true?

In this attitude of mind he took up the review of his book, the Origin of the Earth, when it was to go to its fifth printing. The year was 1925; he was 82. With the wisdom of a veteran but with the courage of youth, he critically revised his earlier postulates—not to prove but to test them—and he came upon "a lion in the path." He had met lions before, such as the doctrine that the rotation of planets, if they were formed from solid accretions, should be backward instead of forward. For a long time that lion had barred the way from the field of gaseous origins to that of the planetesimals, but he had been shown to present a false front. Was this new lion more formidable?

The difficulty lay in the fact that the rotation of a cyclonic bolt must be around the axis of the bolt as it left the sun and would therefore be

directed almost at right angles (67½°) to the actual direction of rotation of the earth. Here was a dynamic contradiction of crucial significance, but, as Chamberlin said: "There was nothing to do but to go right at it." A shift of the axis of rotation was indicated. To a mind seeking catastrophic effects some violent accident might have been suggested, but neither the experience of the student nor the mechanics of the planetary system was consistent with such an assumption. The rotation of the earth had long been attributed to innumerable minute impulses. Similar minute but unsymmetrical impulses due to the infalling planetesimals, and the eccentricity of density which is apparent in the full-grown earth might have caused a creeping of the axis of rotation during the growth of the globe. The suggestion was put to the test of mathematical study and found sound. Thus the lion was overcome.

This illustrates one of the lessons to be learned from Chamberlin's researches; namely, the value attaching to small effects recurring persistently during the ages. His capacity to detect causes of this nature grew out of the constant effort to keep in touch with the realities, all the realities.

Chamberlin's great contributions to science relate to the two extreme stages of the evolution of the earth: The formation of the planet and the subsequent history of its atmosphere. His research also traversed all intermediate phases of terrestrial history, and he cast a long look ahead. He hopefully forecast the evolution of man to higher and higher possibilities, without limitation of time or intellectual development. He himself set the example, advancing far—and beckoning.

The following is a summary of important events in connection with Professor Chamberlin's career:

Place and date of birth: Mattoon, Ill., September 25, 1843.

Occupation: Professor (Emeritus) of Geology, University of Chicago. Research Associate, Carnegie Institution of Washington.

Education and degrees: A. B., Beloit College, 1866, A. M., 1869; graduate, science, University of Michigan, 1868–69; Ph. D., University of Michigan and Wisconsin, 1882; LL. D., University of Michigan, Beloit College, and Columbian University, 1887, University of Wisconsin, 1904, Toronto University, 1913; Sc. D., University of Illinois, 1905, University of Wisconsin, 1920.

Marriage and children: Married Alma Isabel Wilson, 1867 (deceased). One son, Rollin Thomas Chamberlin.

Chief Publications: Geology of Wisconsin; Treatise on Geology (with R. D. Salisbury), 1906; The Origin of the Earth, 1916. Numerous scientific and educational articles. Editor of the Journal of Geology.

Public offices, commissions, or positions of honor or trust:

On Wisconsin Geological Survey, 1873–1882, first assistant, later director.

Special commission to study the state of scientific education in China, 1908–9.

Trustee, Beloit College.

Commissioner, Illinois Geological Survey, until 1919.

Consulting geologist, United States Geological Survey, 1908.

Research associate, Carnegie Institution of Washington.

Honors or decorations conferred:

Medal for geological publications, Paris Exposition of 1878.

Medal for geological publications, Paris Exposition of 1893.

Helen Culver medal of the Geographic Society of Chicago.

Bust of Thomas Chrowder Chamberlin presented to the University of Chicago, February 7, 1903, "in recognition of the eminent services of Professor Chamberlin to the science of geology."

Portrait of Professor Chamberlin presented to the University of Chicago on June 11, 1918.

Hayden medal awarded by the Academy of Natural Sciences of Philadelphia, for distinguished work in geology, 1920.

Penrose medal, Society of Economic Geologists, 1924.

Penrose medal, Geological Society of America, 1927.

Membership in technical, scientific, or professional societies:

Wisconsin Academy of Science, Arts, and Letters (president, 1885–1887).

Geological Society of America (president, 1895).

Chicago Academy of Science (president for 18 years, 1897–1915).

Illinois Academy of Science (president, 1907).

American Association for the Advancement of Science (president, 1908–9).

National Academy of Sciences.

American Academy of Arts and Sciences, Boston.

Geological Society of Washington.

Philosophical Society of Washington.

American Philosophical Society, Philadelphia.

Correspondent of the Academy of Natural Sciences of Philadelphia.

Corresponding member, British Association for the Advancement of Science

Corresponding member, Geological Society of Edinburgh.

Corresponding member, Geological Society of London.

Corresponding member, Geological Society of Sweden.

Corresponding member, Geological Society of Belgium.

Corresponding member, New York Academy of Science.

Sigma Xi.

Phi Beta Kappa.

Professional or business record:

1866–1868. Principal Delavan High School.

1869–1872. Professor of natural science, State Normal School, Whitewater, Wis.

1873–1882. Professor of geology, Beloit College.

1873–1876. Assistant geologist, Wisconsin Geological Survey.

1876–1882. Chief geologist, Wisconsin Geological Survey.

1878. Made a study of glaciers in Switzerland.

1882–1886. Geologist, United States Geological Survey, glacial division.

1882–1907. Made a study of the glacial formations of America, under the United States Geological Survey.

1885–1887. Professor of geology, Columbian University.

1887–1892. President, University of Wisconsin.

1892–1919. Head, department of geology, University of Chicago.

1892–1928. Senior editor, Journal of Geology.

1894. Geologist to Peary Relief Expedition—made a study of glaciers in Greenland.

Contributed chapters on North American glaciation to Geikie's "Great Ice Age."

1902–1909. Investigator, fundamental problems of geology, Carnegie Institution of Washington.

Consulting geologist, Wisconsin Geological Survey.

1908—. Consulting geologist, United States Geological Survey.

1909–1928. Research associate, Carnegie Institution of Washington.

1909. Made a study of fundamental principles of geology, especially the study of the old hypotheses of the origin of the earth and the solar system, destructive criticism of these (in connection with F. R. Moulton) and their final rejection. and the development of an entirely new hypothesis now known as the planetesimal hypothesis. This view has been widely, though as yet not universally, accepted. It is perhaps Doctor Chamberlin's greatest contribution to science.

Developed a radically new view of the history of the atmosphere (from a key derived from G. Johnstone Stoney).

Made a study of tidal problems.

Carried on diastrophic studies, basing the great epochs of earth history on changes in the body of the earth.

1919–1928. Professor emeritus, department of geology, University of Chicago.

HIDEYO NOGUCHI

1876–1928

HIDEYO NOGUCHI[1]

By Simon Flexner

The Rockefeller Institute for Medical Research, New York

[With 1 plate]

Hideyo Noguchi was born on November 24, 1876, in Inawashiro, Fukushima, a village in the mountains of northern Japan. His name during childhood was Seisaku which, as is the custom in his country, was changed to another when he reached manhood. The adoption of the name "Hideyo" gives us an insight into the way his budding mental powers impressed those about him, for of the two parts composing the word, "Hide" means superior or eminent, and "yo" means world. The prophecy carried by the name came to a remarkable realization as subsequent events showed.

Noguchi graduated from the local academy at Aizu in 1889, receiving during this period a preliminary introduction into medical practice. The circumstances of his early schooling are delightfully set forth in an account prepared by his teacher and foster-father, Sakae Kobayashi, which was used in connection with the memorial exercises held in Doctor Noguchi's honor in his native village.

According to this account, Noguchi belonged to a family which had become greatly impoverished. After the restoration of the Meiji, Mr. Kobayashi, a samurai of the Aizu clan, being learned in the Chinese classics, entered the teaching profession and became principal of the higher school (academy) at Inawashiro, with which were affiliated a number of more elementary schools of the neighboring villages.

The principal visited these lower schools, and on one occasion while examining the children at Sanjogata, his interest was aroused in an ill-clad pupil whose left hand was badly deformed. On inquiry it developed that at the age of two years the hand had been severely burned, and the primitive medical treatment had left the fingers, while not completely lost, yet grown together and almost useless.

[1] The substance of this sketch was adopted as a minute for the records of the Board of Scientific Directors of the Rockefeller Institute for Medical Research. Reprinted by permission from Science, June 28, 1929.

The physically backward child Seisaku gave his age as 14, and explained that, because of the poverty of his family, he would be obliged to leave school. On learning that, in spite of having entered the school a year or two later than the other pupils, his progress had been so rapid that he had surpassed them all, the principal had him transferred to his own school at Inawashiro.

A day was fixed on which Seisaku was brought to Mr. Kobayashi's house by his mother. The child astonished the teacher by going at once to the altar of Buddha, found in many Japanese houses, kneeling before it and repeating a little prayer before saluting the principal. As is customary in the East, the mother brought with her a present which she tendered the teacher. It consisted of a few fresh-water shrimp, caught doubtless by herself in the adjacent lake.

Seisaku responded quickly to the new environment, making rapid progress in his studies and growing strong in body and daring in temperament. It is recorded that he would fight and even defeat other boys of his class with his single, uninjured arm. However, the deformity of his left hand constantly vexed him and he considered many ways of having it corrected.

Just at this time and while Noguchi's course after graduation was being considered, there came to the neighboring city of Wakamatsu, Dr. Kanae Watanabe, whom Noguchi consulted. Separation of the fingers was undertaken and successfully accomplished, and during the two weeks of residence in the doctor's household, while the treatment was being carried out, Noguchi decided to become a doctor. He continued with Doctor Watanabe, serving as errand boy and apprentice, and when the China-Japanese War broke out and the doctor, an ex-military surgeon, returned to the army, the young Noguchi was left in charge of the household affairs and medical practice.

With a strange forecast of the future, Noguchi immediately arranged with a middle-school teacher for lessons in German and with a French missionary for lessons in French, endeavoring at the same time to make a beginning in English by himself. Curiously enough, he progressed fastest in English, although in time he obtained a reading knowledge of all three languages. This gift for languages persisted, and later he added not only enough Italian and Spanish to enable him to read scientific papers, but during a year's residence in Copenhagen he mastered spoken as well as written Danish. On his several expeditions to South America where he studied yellow fever, he came to converse in Spanish with doctors and officials, which served greatly to extend his personal influence.

It was at this early period in his mental training that he disciplined himself to sleep and work at short intervals. This habit of mind and body, which played a large role in his scientific career, he never subse-

quently relinquished. He would lie on a mat beside his writing desk, and after a few hours of sleep, he would rise and resume study. His wife told me recently that his custom was to repose an hour or two after dinner in a large comfortable chair and then read or write late into the night. The last days before leaving for Africa he was at the Rockefeller Institute almost unintermittently for 48 hours or more, and his letters from Africa were written at the end of long, arduous days and with the dawn stealing into the windows.

Noguchi's mental acumen seems not to have been preceptibly blunted by these excesses. I recall vividly an early morning visit to my home after a night's vigil. I was dressing when word was brought up that Noguchi was waiting. Fearing some catastrophe, I hurried down and found him eager and tense, but not disturbed or excited. He had spent the night in going through a lot of about 200 slides of paretic brain specimens stained for spirochetes. In the early evening he had detected what he thought were spiral organisms. By going over and over all the slides he had put to one side seven in which he believed he had found spirochetae. However, as so many competent histologists had failed in the same quest, he became distrustful of his judgment and sought confirmation. He was induced to take breakfast, after which we went at once to his laboratory where the accuracy of his observations was immediately established. This discovery constitutes a landmark in the pathology of paresis.

In 1894, after the close of the China-Japanese War, Noguchi spent three years at the Tokyo Medical College, graduating in 1897. Probably the lack of means and want of a college degree barred him from the University Medical School. He at once passed the government examinations, became a licensed physician and surgeon, and entered upon an assistantship under Surgeon-General Satow, at the General Hospital, which he held for about eight months. This hospital issued a monthly medical periodical, the editorship of which was intrusted to Noguchi. The linguistic talents recorded above correspond to a literary facility which he retained throughout his life. He came to write his scientific papers in English with an amazing speed, and while they were never faultless, they required far less editorial correction than might have been expected. It was at this time that Noguchi became lecturer in general pathology and oral surgery at the Tokyo Dental College, and his lifelong friendship with Doctor Chiwaki began. This connection continued until he sailed for America, although in September, 1898, Noguchi became assistant to Professor Kitasato, at the Government Institute of Infectious Diseases, an institution based on the institute founded in Berlin for Robert Koch, who was Kitasato's teacher.

Bubonic plague having appeared in China, Noguchi was sent to New Chwang by the International Sanitary Board; he was made

physician in chief to the Central Medical Bureau, which comprised both a hospital and bacteriological laboratory. The plague having disappeared from this region, he was transferred to Manchuria under a Russian medical commission, where he remained until the Boxer outbreak, when he returned to the Institute of Infectious Diseases in Tokyo.

From 1899 until 1900 Noguchi published several textbooks, including volumes on the methods of pathological and bacteriological study, general pathology and morphology of the teeth, and he translated from German into Japanese the first part of Hueppe's popular manual of hygiene.

I come now to the chance meeting which I had with Noguchi in Tokyo. In the spring of 1899, I was sent by the Johns Hopkins University as a member of a medical commission to the Philippines in order to study tropical diseases among American soldiers, and on this occasion I made a visit also to Japan. We requested permission from Professor Kitasato to visit his institute, and the invitation to do so was brought to the hotel by Noguchi. The latter having extended the courteous invitation, expressed a wish to go to the United States to study pathology and bacteriology.

It is only proper to state that no particular encouragement was given to this request. It is desirable to explain that the writer was not returning to the Johns Hopkins Medical School in the autumn, but was about to transfer to the University of Pennsylvania. To avoid embarrassment, Noguchi was asked to write him there. In due time a letter, composed in English which under the circumstances must be regarded as remarkable, arrived.

In the meantime, encouraged by a loan of 500 yen (about $250) from Yashuhei Yako, Noguchi consulted Mr. Kobayashi about his desire to go to America. His teacher is reported to have said to him that "money borrowed is not like money earned. Once it is spent another loan is asked for; hence he would do well to think twice before going abroad on borrowed money." The advice determined Noguchi to earn the necessary money. This accomplished, he went again to his teacher to ask him to look after his parents, brothers, and sisters in his absence. Mr. Kobayashi's account of this incident represents Noguchi as saying, "If I wish to be filial and faithful to the Noguchi family, I feel in duty bound to remain in my country, and so must sacrifice my cherished hope. If I go to America, I must forsake my dear mother. What then am I to do?" Mr. Kobayashi, feeling that no ordinary obstacle should be permitted to prevent the fulfilment of so deep an aspiration, promised to look after the family, whereupon the two friends clasped hands and wept, and Noguchi said, "Allow me in the future to call you father," to which consent was given. Thereafter in his letters Noguchi always addressed Mr.

Kobayashi as "father," and in 1915 on his only return to Japan he entered into a pledge of brotherhood with Mr. Kobayashi's sons and daughters. I have received a letter written a short time before Noguchi sailed for Africa, and its tone and contents show a deep affection for his foster-father and reveal that he was in the habit of keeping him informed of his scientific work. The progress of the studies on trachoma is related in this letter. Mr. Kobayashi is said to have told Noguchi that his three main assets in life arose from his physical deformity, his poverty, and his stubborn will. Mr. Kobayashi wrote after Noguchi's death that he had made a great mark in the world by virtue of these valuable circumstances.

His life has been a long series of struggles, and when he died a dramatic death in West Africa in pursuit of knowledge, a great storm was raging. Providence did not give him peace even on the verge of death, for Seisaku, the child, had dreaded above everything—thunder.

Noguchi arrived in Philadelphia at the end of 1899 under circumstances not too auspicious. He presented himself at the dormitories of the University of Pennsylvania unexpectedly, and in accordance with eastern custom bearing several gifts, which the writer still possesses and cherishes. It developed that the most immediately pressing question would be that of financial support. The small capital with which Noguchi started on his enterprising voyage had been all but exhausted by the expenses of the long journey. University funds for his support there were none; inquiry among Japanese officials brought only disappointment. Hence there was one thing only to do, namely, to start work and to wait for something to turn up. A theme in bacteriology was chosen and work begun in the cramped quarters allotted to pathology in the old medical building. Providence was, however, not unkind, and before long a patron was found.

A short time before Noguchi's arrival, Dr. Weir Mitchell, whose contributions to the nature and action of the venoms are famous, had conceived the notion of a further study along the lines of immunology which was then a fresh and advancing subject. He and the writer had discussed this undertaking and were awaiting a suitable opportunity to make a start.

The matter was now presented to Noguchi, who fell in with the idea, confessing of course that he knew nothing whatever of venoms and next to nothing of the methods of immunology. Doctor Mitchell provided funds, which at the outset just sufficed for the experiments and a modest sum for Noguchi's living. It was a period of strenuous endeavor and simple living for him, but Noguchi's long struggle with adverse conditions in Japan made it one of no great hardship. The first lot of rattlesnakes, magnificent specimens, shipped from Florida, was killed by cold, but Doctor Mitchell soon secured others, and the study was not only begun but quickly began to yield illuminating

results. It was not long before Doctor Mitchell interested the National Academy of Sciences, which made contributions from the Bache Fund to extend the scope of the investigation, and somewhat later he interested the Carnegie Institution of Washington, which made liberal grants. As each special topic of research was completed it was published in the University of Pennsylvania Medical Bulletin or elsewhere, and finally the results of the studies as a whole were brought together in a handsome volume, freely illustrated, brought out by the Carnegie Institution. Noguchi undertook the preparation of this volume in English, and it is a tribute to his talents as a linguist that in spite of the almost herculean task the editorial revision required was not great. This writing facility persisted and was perfected as the years went on. Noguchi came to produce English manuscripts not only as readily as a trained English writer but even more quickly than most writers, and he would write clearly under considerable pressure of work and time. His powers in this direction were distinctly unusual, since he wrote well and accurately at periods when his days were given to arduous laboratory work and his nights to little sleep. His last finished large work, namely, the remarkable monograph on trachoma, was produced under this kind of stress, while he was preparing for the African expedition.

There can be no doubt that Noguchi was highly gifted as an investigator nor that his true medium of research was the biological field. He was fortunate in entering it at a rewarding period of bacteriological and immunological advance. But it is probable that his peculiar talent in meeting obstacles and overcoming them by insight and technical skill would have brought him to the front at another period, and in another branch of biological investigation. Noguchi's exceptional powers arose from a threefold union of natural abilities: he was gifted with a clear, apprehensive mind; his technical skill was phenomenal; his industry was extraordinary. His perspicacious intellect enabled him to state a problem sharply; his resourcefulness in devising means to ends prevented him from being blocked by methodical obstacles; his inexhaustible industry and physical prowess, which often made virtually two days of one, immensely extended the range of his activities. If we add to this formidable list of qualities the fact that his mind was many tracked, in the sense that he would keep several major problems moving at the same time, we may begin to get an insight into the secrets which determined Noguchi's remarkable productivity, which tended to become speedier as the years advanced and experience became richer. To a visitor who happened into his laboratory late at night and inquired whether he ever went home he is said to have replied, "Home? Why this is my home."

The department of pathology of the University of Pennsylvania between 1900 and 1903 was carrying a heavy burden of routine, while the staff was young and small in size. Noguchi was exempted from these duties, not only because of the bar of language, but because his talents as an investigator were apparent to his colleagues, who admired him for his gifts and loved him for his ingratiating personal qualities. Very soon Noguchi was a marked man throughout the university, and even throughout the world. These captivating individual traits never diminished. Every one who came within their influence felt them and was impressed with a kind of noble simplicity and dignity of personality which scientific success, no matter how great, never impaired. Part of his outstanding position as a world figure arose from a kind of living charm of manner and conduct, raised of course to high power by his eminence as a scientific investigator.

The Rockefeller Institute for Medical Research in New York was opened in 1904. The year intervening between the transition of Noguchi from the University of Pennsylvania to New York was spent by him in Copenhagen. The choice of place to study was determined by the recent publications of Madsen and Arrhenius on immunochemistry, in which it was sought to range immunological processes with physicochemical reactions. Noguchi already possessed an understanding of the opposing chemical view, as embraced in the side chain theory of Ehrlich. The incident led, however, to a misunderstanding not without diverting features. Ehrlich had praised the venom work, which fitted in well with his theory; hence he interpreted Noguchi's choice of Copenhagen as a criticism and defection. All this came out one day in Emil Fischer's laboratory in Berlin, where the writer was spending a semester. Ehrlich walked him up and down in the aisle between the long rows of work tables expostulating ever more excitedly. At the height of the exhortation, which had stopped all work going on in the room, Fischer entered from his private laboratory, having been attracted by the uproar. The two friends greeted each other warmly, and Ehrlich, realizing the commotion he had caused, laughed and said to Fischer, "Why do you not have me thrown out?" To which the latter replied, "Oh, we are very tolerant here." Ehrlich accepted the explanation offered and nothing more came of the episode. Noguchi remained rather in the Ehrlich camp of immunologists, although he concerned himself little with the merely theoretical basis of immunity. With the opening of the Rockefeller Institute, Noguchi continued for a time his studies on the Wassermann reaction begun with Madsen, and devised a new method for its application in which an antihuman system is employed. Valuable as this contribution proved to be,

its significance is small compared to the by-product it yielded, namely the pure cultivation of the class of spirochetal microorganisms.

This class of spiral organisms had become clinically enhanced in importance through the discovery of the syphilis and yaws spirals. They, together with known spirals of other sorts inhabiting various organs, were recognized wholly through their microscopic characters. All efforts to secure them in pure, artificial cultivation had failed. Noguchi set himself to this task, which he accomplished in a brilliant manner. The entry into this field of bacteriological research was to prove his most important, as well as daring venture, because so many of his subsequent discoveries were reared on the mastery of the technical means of cultivation which he secured in working with the spirochetae.

In essence, the method was invented by Theobald Smith, and it consisted in employing a culture medium in which a fragment of a sterile, normal organ (rabbit kidney) had been placed. Noguchi had to modify the original medium in many ways to adapt it to the cultivation of the many spiral and other microorganisms which he obtained in pure form for the first time. Even for the class of spirals the culture requirements are various, while when the method was applied to the growth of still other organisms, e. g., globoid bodies in poliomyelitis, *Bacterium granulosis* in trachoma, profound modifications became necessary. Still it remains true that he found in the principle of employing fresh, sterile tissues in addition to the more common culture media, as introduced by Doctor Smith, the key which was to unlock many bacteriological doors previously unopened.

The cultivation of the parasitic spirals, including the syphilis spiral, proved, of course, clinically most significant; but in addition to more than half a dozen pathogenic species, he cultivated pure for the first time as many merely saprophytic species living in or on the bodies of animals. The culture of the syphilis spiral was made to yield luetin, a soluble extract based on tuberculin, of use in detecting latent and congenital syphilis.

There is no better incident than this to bring out Noguchi's almost faultless and infinitely varied technical skill. The culture medium we are considering is not only very variable in itself, because of the chemical complexity of the materials entering into its composition, and therefore exceedingly difficult to keep approximately constant, but it demands constant modification in order to adapt it to the many organisms the cultivation of which he accomplished through its use. It is no wonder, therefore, that so many of Noguchi's would-be followers have failed in their efforts. Several years had, indeed, to elapse before his work was repeated by others and began to become widely fruitful. The belief became current that the methods had not been fully disclosed. There is no doubt that Noguchi did always

describe them as fully as language permitted. With factors so variable in their nature, what he perhaps did not do, and what such consummate masters of technique almost never find it possible to do, is to put into words those subtle, imponderable yet essential twists and turns of method used by them, often unconsciously, in adapting a medium to a recalcitrant microorganism. The patient and resourceful among bacteriologists have learned in time to repeat what Noguchi has done, but the mass of the conventional among them undoubtedly soon tired and gave up the unequal contest.

In 1912 Noguchi married Mary Dardis, whom he surrounded with devotion and who, on his perilous journeys, as we learn from letters and cable messages, he had constantly in his mind, lest she suffer from undue anxiety. He required few diversions in order to refresh his spirit. An occasional game of chess at the Nippon Club or at his home or an evening with friends sufficed. In the summer at his bungalow in the Catskills he fished in the stream which ran beside his little place, or he painted in oils in a self-taught manner in which there were both talent and charm. In earlier days he was skillful with the brush and produced water-color illustrations for his published papers, which were faithful, finished, and original. As his mind was too restless to renew itself by idleness, he found in these simple devices means to restore his strength. These avocations were followed purely for refreshment, and he always took himself humorously as painter or sportsman.

The last 10 years of Noguchi's life were spent in the investigation of certain obscure diseases, including yellow fever, trachoma, Rocky Mountain spotted fever, poliomyelitis, rabies, kala-azar, and Oroya fever and verruga peruana. It is true, of course, that he did not find solutions of all these riddles of pathology, but the remarkable thing is rather that he should have solved as many of them as he did.

There was a logic in Noguchi's work which is not always perceived immediately by readers of his monographs and many papers. As a matter of fact he was always capitalizing and refining his experience. He learned that the gonads of the rabbit not only serve to grow the syphilis spirochete in great numbers, but also to free them of associated, contaminating bacteria. His studies on Rocky Mountain spotted fever emphasized further the suitability of these organs to the abundant multiplication of even undetermined microorganisms. He therefore employed the method to enrich and purify vaccine virus, and thus for the first time secured this important material in an uncontaminated state. The neurovaccine, so widely employed in Europe for vaccination is, of course, a direct outgrowth of Noguchi's discovery, as are many of the studies now in progress in which particular organs of living animals are used to procure evidences of the presence of parasitic organisms in diseases of unestablished origin.

In 1918 Noguchi became a member of the commission sent by the Rockefeller Foundation to Guayaquil, Ecuador, to investigate yellow fever. This was the first of four expeditions made by him to South America between 1918 and 1924. On each expedition he isolated in culture a spiral organism from cases diagnosed as yellow fever which he subsequently named *Leptospira icteroides*. He came to regard this spiral, which he recognized as biologically related to the spiral organism of infectious or hemorrhagic jaundice, as the parasitic incitant of yellow fever. In all his studies he secured the spiral only in a part of the cases examined—6 of 27 in Guayaquil—but he detected evidences in the blood of other cases of the presence of the spiral at some time. This spiral was found afterwards by other bacteriologists by the employment of Noguchi's technique. However, there were many failures also to confirm his findings. At the present moment, Noguchi's work on yellow fever in South America has come into question, so that it is desirable to perceive clearly just what the question is. There is no doubt that Noguchi and others cultivated *Leptospira icteroides* from the cases diagnosed by clinical experts as yellow fever, and with the cultures reproduced in animals symptoms and pathological changes resembling those of yellow fever in man. Now that the extensive investigations of African yellow fever by Adrian Stokes and others have failed to reveal the leptospira and have yielded a filter-passing virus, believed to be the incitant of the disease, and the reinvestigation of South American yellow fever is offering results tending to confirm the African findings, there is inclination to discredit Noguchi's earlier studies. There is really no conflict between the two classes of findings—the only conflict possible arises from the interpretation to be placed upon each. Recent experience, gained with full knowledge of the existence of the filterable virus, has reestablished the occurrence of leptospira in the blood of yellow-fever patients. The future alone can determine whether cases of another infectious disease, due to leptospira, have been and still are confused clinically with yellow fever, or whether in yellow fever a second pathogenic leptospiral microorganism sometimes invades the blood. Such instances of secondary or concomitant infection are, of course, known to arise in other defined or specific diseases.

In 1925 Dr. T. Battistini, of Lima, came to study with Noguchi under a Rockefeller Foundation fellowship. He brought with him a sample of blood taken from a case of Oroya fever. This circumstance enabled Noguchi to turn his attention to the rod-shaped bodies found by Doctor Barton in 1905 in the red corpuscles of persons suffering from the disease. These bodies had not been secured in artificial culture and were looked upon not as bacteria but as protozoa. Noguchi threw himself into this problem with characteristic energy, and the

solution which he found was undoubtedly aided by the fact, already determined in 1910, that the warty or verrugous lesions appearing on the skin bear a relationship, if a disputed one, to Oroya fever, and they had actually been already communicated by inoculation to monkeys. It was, indeed, this disputed relationship which led the Peruvian medical student, Carrion, in 1885 to inoculate himself with material taken from the warty formations, from which a fatal attack of Oroya fever developed. Since this time the composite malady is often called Carrion's disease.

The rods yielded to artificial cultivation, and with the cultures Noguchi was enabled to reproduce both verruga peruana and the equivalent of Oroya fever in monkeys. Moreover, the rods have been cultivated repeatedly from verrugous nodules sent to New York from Peru. The bacterial incitant of Carrion's disease having been established, Noguchi turned his attention to the manner in which infection arises.

A good many acute observations made by Peruvian physicians and others had already indicated that direct transmission from person to person did not occur. Indirect evidence, indeed, pointed to an insect carrier or vector of the microorganism. An American entomologist, Charles H. Townsend, who had studied the subject minutely had concluded that this vector belonged to the phlebotomus class of nocturnal blood-sucking insects. He even went so far as to name the supposed vector *Phlebotomus verrucarum*.

Just before sailing for Africa, Noguchi planned a definitive investigation of this question. Through the cooperation of the Rockefeller Foundation, Raymond C. Shannon was sent to Peru to study the insect life of the valleys in which verrugas and Oroya fever abound. He was to collect and send insects falling under suspicion to New York, where the inoculation and culture experiments were to be made. All this was carried out precisely as Noguchi had arranged it, with the result that the vectors of Carrion's disease have now been determined to be insects of the class of phlebotomi, as Townsend believed, and Shannon has succeeded in identifying two species, *P. verrucarum* and *P. noguchii*, which certainly carry *Bartonella bacilliformis*, and a third species, *P. peruensis*, which is in this respect still in doubt.

Noguchi's investigations of trachoma fall into two periods. The first one dates from 1910 to 1913, in which he studied cases of the disease in New York. Nothing especially significant came from this study. But the investigation made in 1926 of cases of Indian trachoma at Albuquerque, N. Mex., led to a wholly different result. This investigation was promoted by Dr. F. I. Proctor and Dr. Polk Richards, who gave invaluable aid. The plan which Noguchi followed was to make cultures on specially prepared media and to isolate and test by inoculation into the conjunctiva of the monkey all bacteria growing in the

cultures. He decided not to overlook any microorganism, no matter how banal it appeared to be. This determination in itself is illuminating as to Noguchi's method of attacking a new, complex problem. To most bacteriologists the labor involved would seem not only futile but devastating. Just here we observe not only the rigid system of research which Noguchi had developed, but we note also the effect of his incomparable industry, because the mere technical operations of the plan proved prodigious. They did not, however, abate his decision, and the end result is that he discovered a new bacterial species called *Bacterium granulosis*, which on injection into the conjunctival mucous membrane of the chimpanzee, baboon, and *Macaca rhesus* induces a chronic granular infection, which clinically and pathologically is indistinguishable from trachoma in man. From the inoculated conjunctiva of one eye the granular infection spreads of itself to the uninoculated other eye. This experimental trachoma in monkeys persists for many months, gradually producing in certain animals the deforming scarlike changes so commonly met with in man. As is so common an experience when a disease native in one animal species is grafted on a species in which it does not naturally occur, there are certain distinctions, usually of intensity, to be detected, but the essential trachomatous process arises in the monkeys as the result of the inoculation of a particular bacterial species hitherto unknown, and obtained by Noguchi from undoubted cases of trachoma as it exists on a wide and destructive scale among the American Indian population.

From time to time, Noguchi undertook the investigation of other problems than those already noted, with which he made progress. Thus the cultivation of the "globoid bodies" from the filter-passing virus disease poliomyelitis was a definite achievement. He contributed to the knowledge of Rocky Mountain spotted fever, both in respect to the Rickettsia-like organisms present in the insect vector, the wood tick, and in human tissues, and also in respect to an antiserum capable of neutralizing the virulent incitant, and thus making the effective treatment of the fatal disease a matter of hopeful further pursuit. His study of the protozoan organism causing kala-azar, a disease of the eastern world, led to the perfection of methods for cultivating the class of flagellated organisms and among them the interesting species inhabiting the latex of the milkweed, which are found also in the intestines of the insects feeding on the milk. Having secured a wide variety of flagellates in pure culture, he developed methods for their distinction by serological and other means such as are used in the differentiation of bacteria.

In October, 1927, Noguchi sailed for Africa. This was the consummation of a wish he had long entertained, but which uncertain health had caused to be deferred. He wished naturally to study and compare the yellow fever of Africa with that of South America. The investi-

gation of yellow fever by the Rockefeller Foundation as a world problem had led to the dispatch of a series of pathologists to Africa, among whom was Adrian Stokes, who, just before his death from yellow fever, had determined the existence of a filter-passing virus in the African disease. On the other hand, the leptospira had not been found in the blood of cases, as had been done in South America. This discrepancy only served to increase Noguchi's desire to study the African fever at first hand. As his health had meanwhile improved, there seemed no sufficient reason for denying him this satisfaction.

Noguchi arrived in Accra, on the Gold Coast, on November 17, and decided to establish his laboratory there. The British officials cooperated in every way, and through the aid of the Rockefeller Foundation staff at Lagos, who lent all assistance, he soon had provision for monkeys and for laboratory work meeting all his requirements. Noguchi had completed his African studies which, among other things, confirmed Stokes's discovery of a virus and failed to yield *Leptospira icteroides;* and he was all but ready to embark for home when he was himself attacked by yellow fever. He paid a visit to the Lagos station on May 10, being apparently in perfect health and showing the greatest interest in the work going on there. He returned to Accra on May 12 and was already ill. The symptoms increased in intensity, and although there was a temporary improvement, alarming symptoms reappeared and his death occurred on May 21, 1928. Dr. William A. Young, the British pathologist at the Accra station who undertook to look after Noguchi's incomplete experiments, himself fell a victim to yellow fever, from which he died on May 29. Stokes, Noguchi, Young gave their lives in the pioneer work of establishing the nature of African yellow fever which had hitherto been one of the baffling problems of tropical pathology.

Noguchi was an international figure much beloved. His sudden death, therefore, came as a shock to the whole world. In virtue of the world-wide scale on which he carried out his fruitful investigations, he had become known as a leader and pathfinder in bacteriology. Messages of sympathy and admiration were sent from far and near, and the circumstances of his courageous and tragic death became the theme of writers in innumerable lay and technical journals.

As is often observed among men of his race, Noguchi was of small stature and slender build, but his physical movements were extraordinarily alert and precise. He carried his well-shaped head surmounted by a heavy growth of black hair erect on strong shoulders, and his well-molded features were dominated and lit up by eyes of unusual eagerness and quickness of glance. His expression was genial and almost never severe, although Mr. Konenkov has caught the latter mood in the portrait bust for which Noguchi sat during

the last days before sailing for Africa. There was striking disproportion between the slight body and the dynamic energy which characterized Noguchi's years of devotion to the main passion of his life—science.

During Noguchi's eventful life, learned societies and governments may almost be said to have vied with one another in doing him honor. The emperor of his own country decorated him twice; in 1915, on his only return to his native country, when he was hailed as one of the most famous Japanese of all time; and again after his death, in special recognition of his eminence and meritorious service to the cause of science, the Order of the Rising Sun of the highest class was conferred upon him posthumously. Noguchi's simple origin and inauspicious beginnings as well as his amazing career in science have been seized upon and held up to his countrymen as worthy of admiration and emulation. His example of filial piety to this family and his teacher, and the story of his visit to his home in 1915, which became virtually a triumphant tour through the country, are being woven into a legend of singular beauty so precious to the heart of the East.

The birthplace of Noguchi has been acquired and will be saved to posterity. As a shrine in which personal effects, mementoes and records of his scientific work will be deposited and preserved, it will become an object of pilgrimage and veneration for the intellectually devout from far and near. The spirit of science will surely hover over this shrine, and in accordance with the genius of his countrymen, it will attract worshipers to whom the name of Hideyo Noguchi will be a sacred emblem of love of his fellow man.

INDEX

A

C

G

H

L

M

W

X

Y

Z